

NASA Contractor Report 182296 - Vol-1

Shear Flow Control of Cold
and Heated Rectangular Jets
by Mechanical Tabs

Vol. I - Results and Discussion

NASA CR-182296-Vol-1) SHEAR FLOW CONTROL OF COLD AND HEATED RECTANGULAR JETS BY MECHANICAL TABS. VOLUME 1: RESULTS AND DISCUSSION (Lockheed Aeronautical Systems Co.) 357 p LIMIT DOMESTIC X89-10470
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W.H. Brown and K.K. Ahuja

Prepared for
Lewis Research Center
under Contract NAS3-25409

May 1989

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FOREWORD

This report was prepared by Lockheed Aeronautical Systems Company, Marietta, Georgia, for NASA Lewis Research Center, Cleveland, Ohio, under contract NAS3-25409 entitled "Jet Mixing Enhancement through Mechanical Perturbations."

NASA Project Manager was Mr. M. Vanco. Dr. K.K. Ahuja was the Lockheed Program Manager, and the principal investigator of this program was Mr. W.H. Brown.

The authors are particularly grateful to Mr. D.E. Lilley of LASC-Georgia for his invaluable help in writing computer programs used to document the results in this report. Assistance received from Messrs. R.H. Burrin and C.R. Huie is also gratefully acknowledged.

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SUMMARY

The objective of the study described here is to determine the effects of mechanical protrusions on the jet mixing characteristics of rectangular nozzles for heated and unheated subsonic and supersonic jet plumes.

To accomplish these objectives, the characteristics of a rectangular nozzle of aspect ratio 4 without the mechanical protrusions were first studied. Intrusive probes were used to make the flow measurements. Possible errors introduced by intrusive probes in making shear flow measurements were also examined.

Several sizes of mechanical tabs were then tested, configured around the perimeter of the rectangular jet. Both the number and the location of the tabs were varied. From this, the best configuration was selected. The following general conclusions were derived: (1) intrusive probes can produce significant errors in the measurements of the velocity of jets if they are large in diameter and penetrate beyond the jet center; (2) rectangular jets without tabs compared to circular jets of the same exit area provide faster jet mixing; and (3) further mixing enhancement is possible by using mechanical tabs.

1.0 INTRODUCTION

In a recent study by Ahuja and Brown (Reference 1) of Lockheed Aeronautical Systems Company in Georgia, it was found that when small mechanical tabs are placed at the lip of a round nozzle with cold or heated flow, the jet mixing is enhanced considerably. The jet flow velocity is reduced by as much as 50%, and for heated jets, the temperature of the jet is also reduced noticeably. Based on the results from Reference 1, two tabs appear to provide the best general result. For two tabs, the jet centerline temperature, at an axial location of $X = 4D$, was reduced 28 percent.

The present study reported herein is based upon the above results. The objective of the present study was to determine if the mechanical tabs could produce mixing enhancement in rectangular jets and to quantify these effects. A rectangular nozzle with an aspect ratio of 4 and the same exit area as the circular nozzle (Reference 1) was used. Three sizes of tabs were designed. One tab was a scaled version of that used in Reference 1. The test facilities and air supply ducting upstream of the nozzle body were identical to those used in Reference 1. Data for cold as well as heated jets were acquired as a function of tab configurations, tab sizes, and jet Mach numbers.

The results of this effort are reported in two volumes. This volume contains the results and discussion. The test facility, the nozzle, and the tab design are described in Section 2.0. Errors introduced by intrusive probes in making flow measurements are described in Section 3.0. The mixing characteristics of rectangular jets are presented in Section 4.0. This section also includes a comparison of flow development with that of a circular nozzle. The effects of tabs on the mixing characteristics of rectangular nozzles are then described in Section 5.0. Concluding remarks are presented in Section 6.

Volume II contains the measured data such as pressures, total temperatures, and static temperatures, in a tabulated form.

2.0 TEST FACILITIES AND EXPERIMENTAL PROCEDURES

The experiments described here were carried out in Lockheed's Jet Flow Facility where the majority of the aerodynamic data of the previously published Lockheed studies on jet mixing enhancement by acoustic excitation was obtained. A detailed description of this facility can be found in References 2, 3, 4, and 5. A general cross-sectional view of the plenum section is shown in Figure 2.1. The acoustic excitation source shown in the figure was present but was not used in this program.

2.1 Heated Air Supply

In essence, the flow in this facility is heated by a through-flow propane burner up to 1,000 K and pressure ratios exceeding 4. The flow from the burner enters through a 10-inch (25.4 cm) diameter plenum that is followed by a contraction to a 4-inch (10.16 cm) diameter acoustic source section. The test nozzles are mounted on the end of the 4-inch (10.16) diameter section. For the 2-inch (5.08 cm) equivalent diameter nozzles used for most of the work reported herein, the plenum-to-nozzle area ratio was 25.

2.2 Rectangular Nozzle and Tabs

A rectangular nozzle having an aspect ratio (AR) of 4 was used in this study. This nozzle mounts directly on the end of the 4-inch (10.16 cm) diameter duct section. The nozzle translates, over 7 inches (17.78 cm) of length, from this 4-inch diameter circular cross-section to a 3.54 inch (8.99 cm) by 0.866 inch (2.2 cm) rectangular section having the equivalent area of a 2-inch (5.08 cm) diameter circular nozzle as shown in Figure 2.2. The area equivalency of the rectangular nozzle and the circular nozzle permits easy comparison of their flow characteristics.

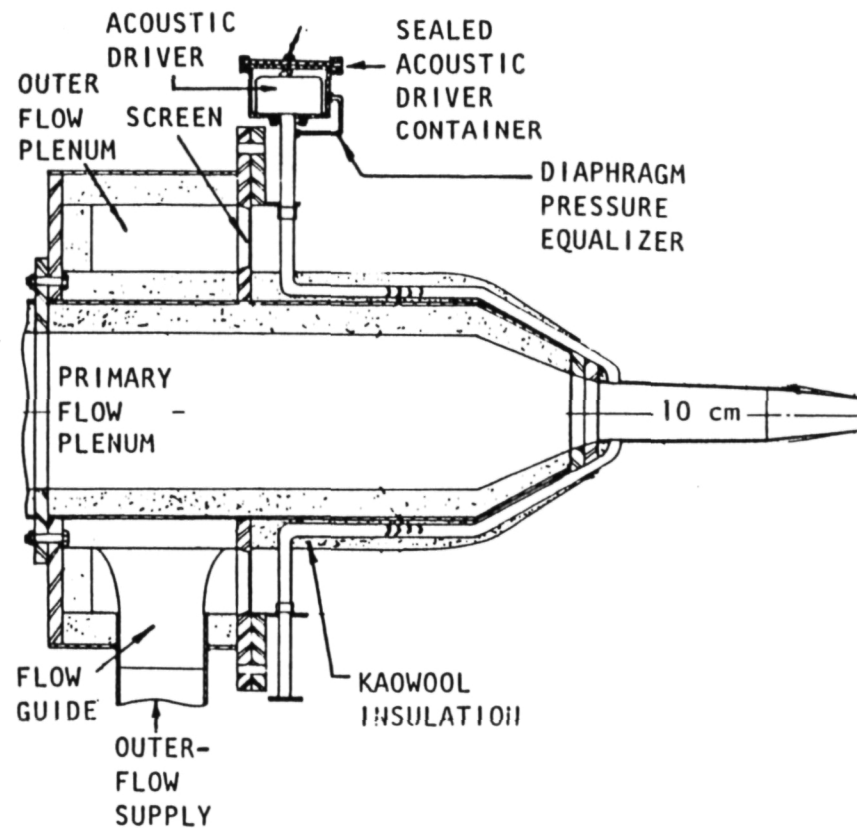


Figure 2.1 Jet Flow Plenum Assembly

NOTE: ① NOZZLE TO BE
FABRICATED FROM 4.0 INCH
SCH 40 SS PIPE WITH
0.25 SS PLATE SIDES
WELDED ON TO MACHINED
PIPE.

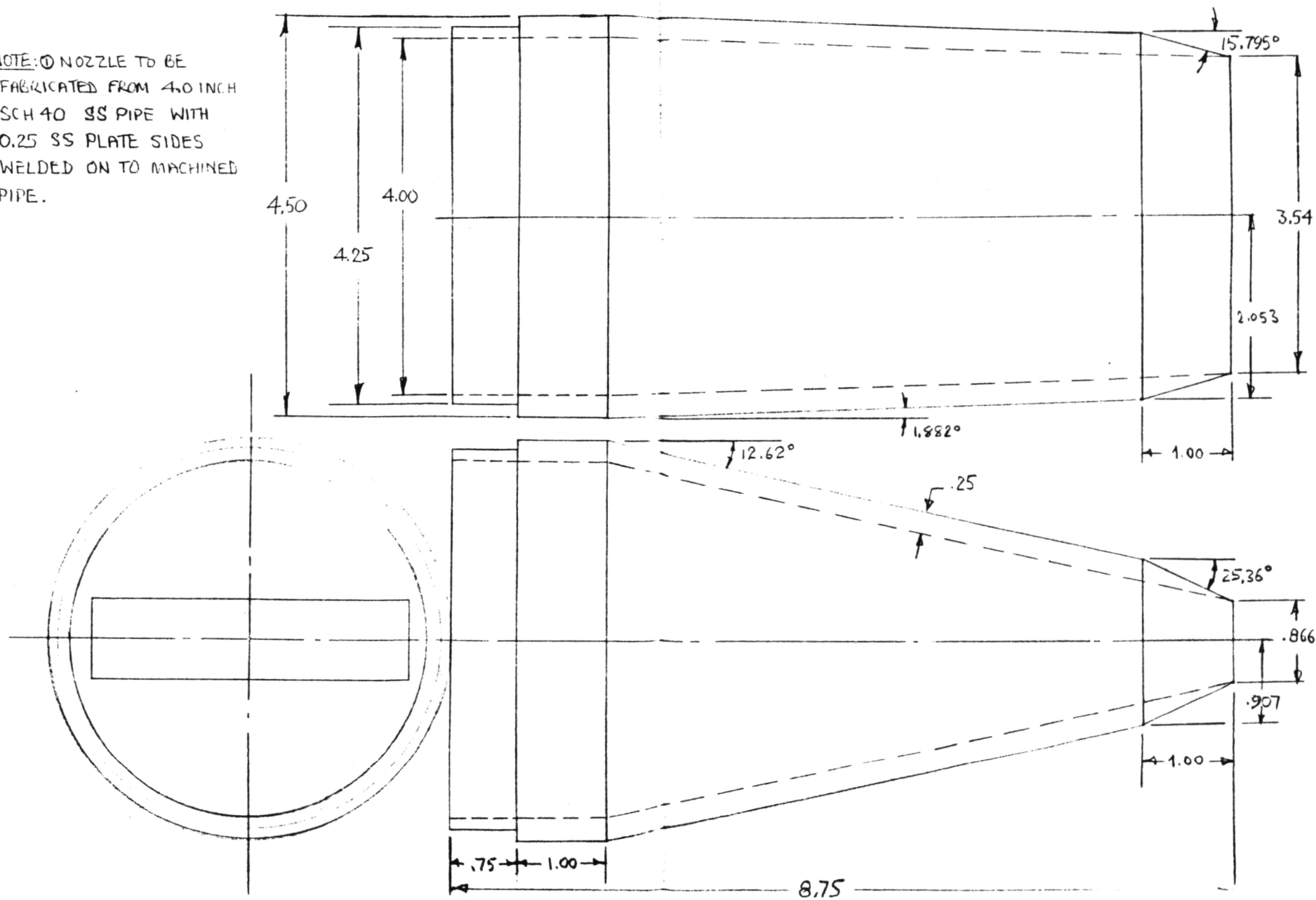


Figure 2.2 Rectangular Nozzle Design

Basically, four sides of a circular section were machined off at the proper angles and replaced by 1/4-inch thick plates that were trimmed to fit. The nozzle was completed by machining a sharp lip on the exit.

Accurate positioning of the tabs at the nozzle exit was provided by an array of mounting holes in the exit and mating hardware on the tabs. As shown in Figure 2.3, a pair of blind mounting holes was provided at each location where a tab might be mounted. One hole was drilled to accept an alignment pin from the tab, and the other was drilled and tapped to accept a screw that completed the alignment of the tab and secured it to the nozzle.

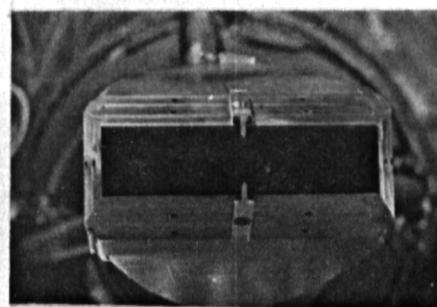
The designs of the tabs are also shown in Figure 2.3. Though not shown in the figure, the screw holes are countersunk so that the outside of the nozzle lip is kept as open as possible.

Various tab configurations that were tested in this program are shown in Figure 2.4, and the exact tab sizes for each configuration are shown in Figure 2.5.

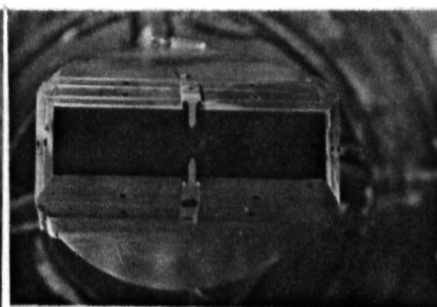
It should be noted that the sizes of tabs designated -A were scaled versions of those used in the in Reference 1 where a 2-inch (5.08 cm) diameter nozzle was used. The tabs used in that study are shown in Figure 2.6 and Figure 2.7.

The tabs for the rectangular nozzle -A configurations, e.g. I-A and IV-A, were scaled using the same ratios of tab dimension to nozzle dimension as those for the circular nozzle but nozzle height or width was used in place of nozzle diameter for tabs on the minor or major axis, respectively. The ratios are given in Section 2.3.

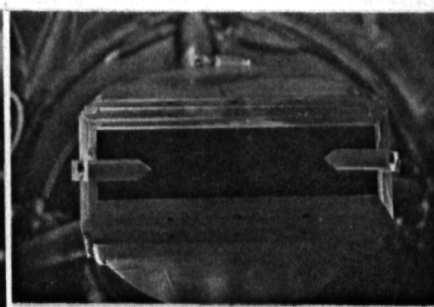
For tabs mounted parallel to the minor axis, the -B tabs are 1.5 times the -A sizes. For those mounted parallel to the major axis, the -B tabs are one-half the size of the -A tabs. Configuration I-C has tabs that



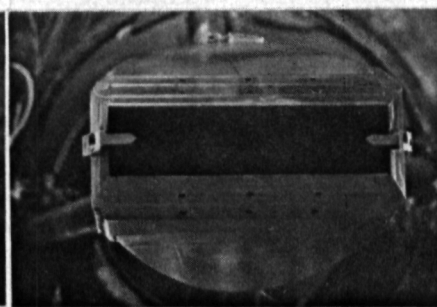
I-A



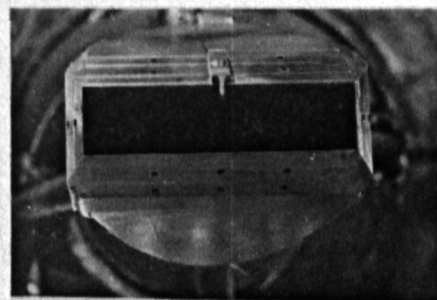
I-B



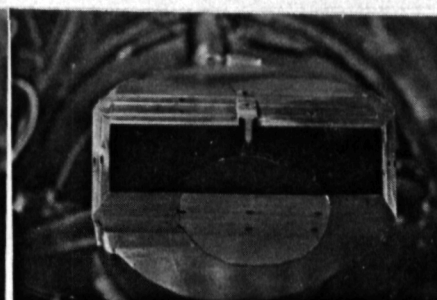
II-A



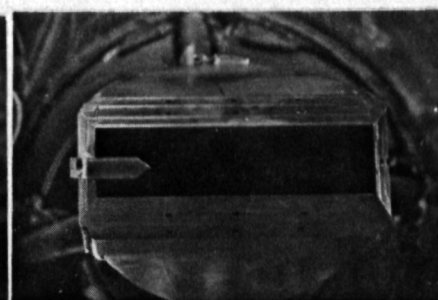
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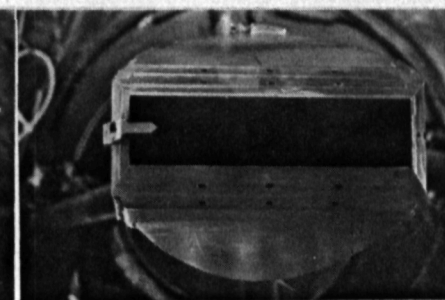
III-A



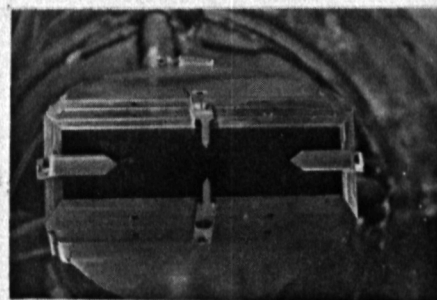
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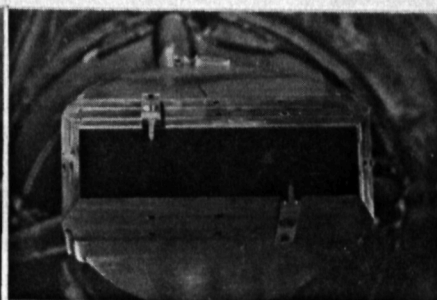
IV-A



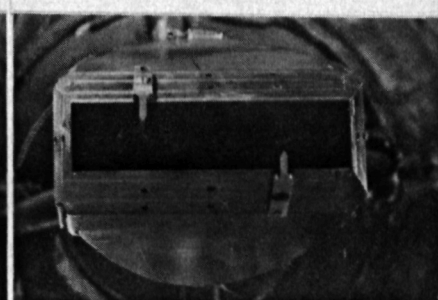
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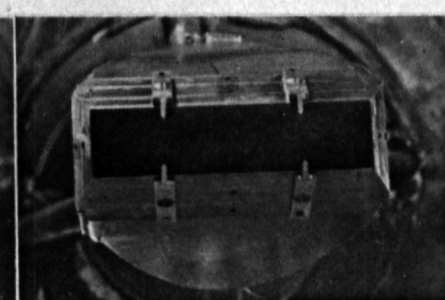
V-C



VI-A



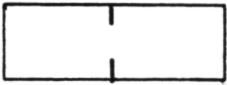
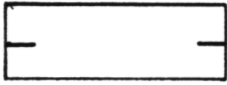
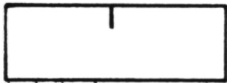
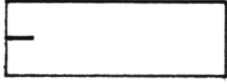
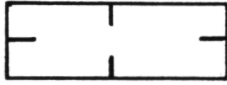
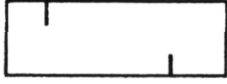
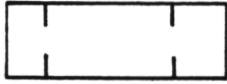
VI-B



VII-A

Figure 2.4

Tab Configurations

CONFIGURATION		MAJOR AXIS		MINOR AXIS	
		w_p	d_p	w_p	d_p
I-A		- - -	- - -	0.066	0.177
I-B		- - -	- - -	0.099	0.265
I-C		- - -	- - -	0.265	0.265
II-A		0.265	0.708	- - -	- - -
II-B		0.133	0.354	- - -	- - -
III-A		- - -	- - -	0.066	0.177
III-B		- - -	- - -	0.132	0.354
IV-A		0.265	0.708	- - -	- - -
IV-B		0.133	0.354	- - -	- - -
V-C		0.265	0.708	0.099	0.265
VI-A		- - -	- - -	0.066	0.177
VI-B		- - -	- - -	0.099	0.265
VII-A		- - -	- - -	0.066	0.177
VII-B		- - -	- - -	0.099	0.265

Dimensions in inches.

Figure 2.5 Tab Dimensions Used in Various Configurations

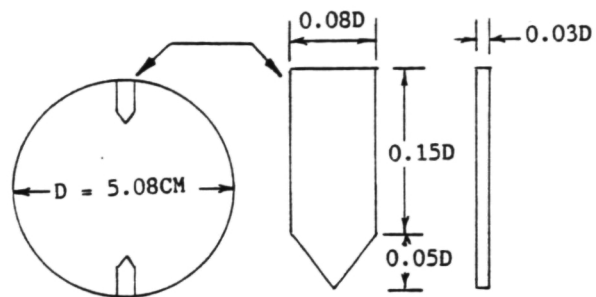


Figure 2.6 Tab Dimensions for Circular Nozzle

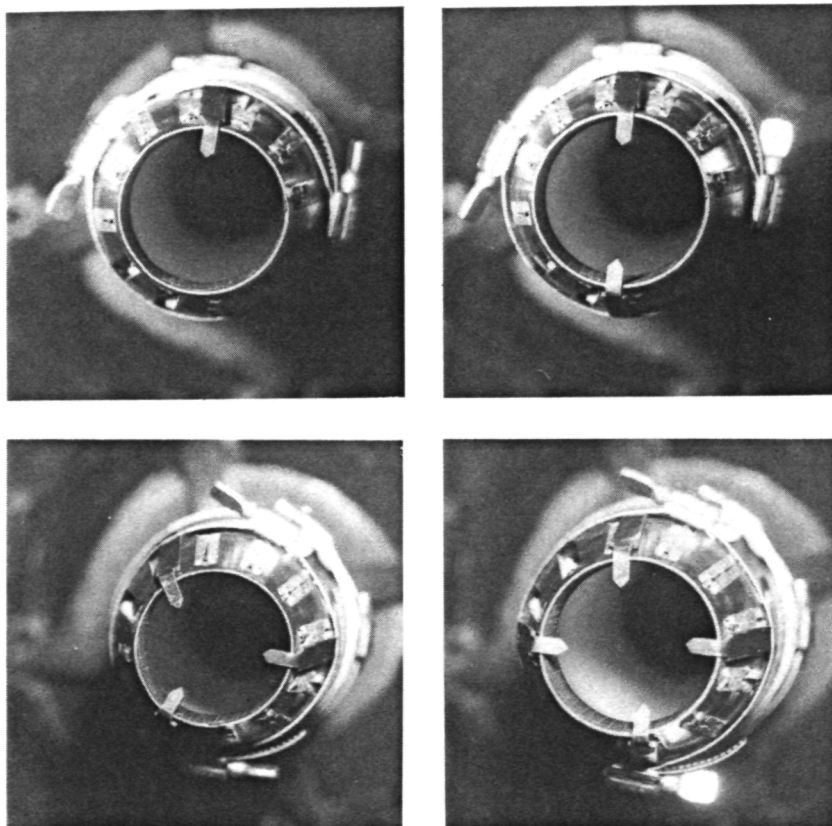


Figure 2.7 Tab Configuration for Circular Nozzle (Ref. 1)

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have both length and width equal to the length of the I-B tabs. Configuration V-C is a combination of I-B and II-A. Thus, tabs of larger and smaller scale than those used in the referenced study were tested.

2.3 Circular Nozzle

The same 2-inch diameter convergent nozzle that was used for the shear flow control experiments reported in Reference 1 was also used in the study for a limited number of tests. The tabs used in those tests were made of 1/16-inch thick stock that was cut to the shape shown in Figure 2.6. The tabs protruded into the jet 0.2 jet diameters (D) and were 0.08D wide. The tabs are shown installed in several configurations in Figure 2.7.

2.4 Nomenclature, Coordinate System, and Traverse Paths

This section presents nomenclature, the coordinate system, and the traverse paths used in Figures 2.8 and 2.9, respectively.

2.4.1 Nomenclature

The terminology and symbols used in this report are given in Appendix A, List of Symbols.

2.4.2 Coordinate System and Traverse Paths

The orthogonal coordinate system has its origin at the center of the nozzle exit plane. The X-coordinate is positive in the downstream direction, the Y-coordinate is positive to the left of the jet axis looking downstream, and the Z-coordinate is positive upwards as shown in Figure 2.8.

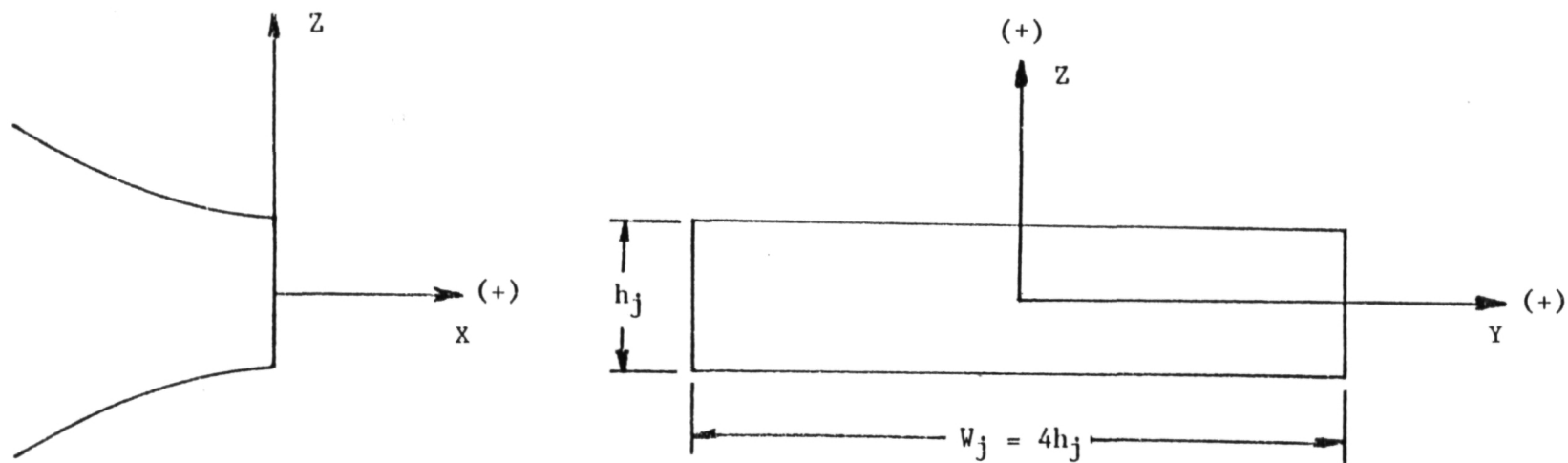


Figure 2.8 Coordinate System

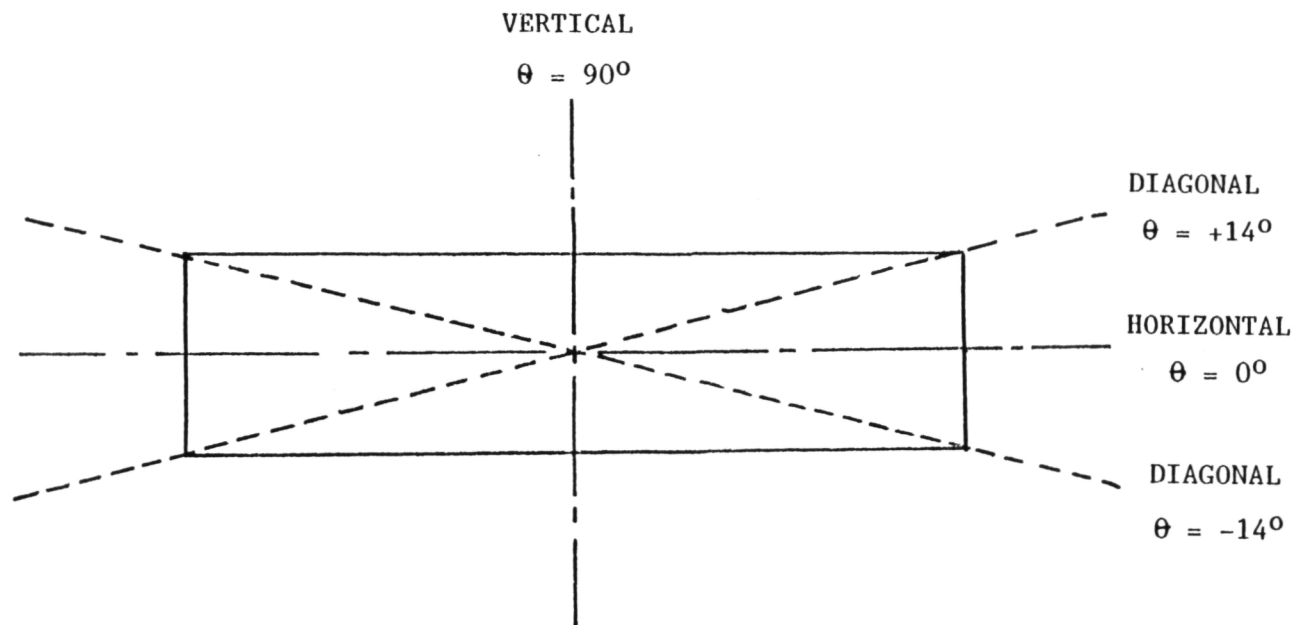


Figure 2.9 Traverse Paths

Horizontal traverses were made through the axis of the jet and parallel to the major axis of the rectangular nozzle. Vertical traverses were made similarly but referenced to the minor axis of the nozzle. Diagonal traverses were made in the horizontal direction but with the nozzle rotated clockwise 14 degrees looking downstream for the -14 degree case and counterclockwise for the +14 degree case. These traverses are shown in Figure 2.9. For the round nozzles, the traverses were simply horizontal or vertical through the jet axis.

2.5 Test Conditions

Test conditions generally included various combinations of jet Mach numbers (M_j) of 0.8 and 1.15; axial position in terms of equivalent jet diameters (D_e) of $X/D_e = 2, 5, 7, 9, 11, 13$, and 15, and temperature ratios (jet total to ambient static) of $T_{jt}/T_o = 1$ and 2.3. Mach numbers for purposes of setting test conditions were calculated from the plenum-to-ambient pressure ratio and assume a fully expanded jet with $\gamma = 1.4$. In the subsequent data reduction operations, Mach numbers were computed using an iterative process that corrected γ for temperature variations by interpolating in a table of gamma versus temperature.

2.5.1 Baseline

The initial set of measurements was made with the baseline nozzle to establish a set of velocity and temperature profiles to which similar profiles for the various tab configurations could be compared. The nominal conditions and corresponding run numbers are given in Figure 2.10.

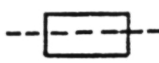
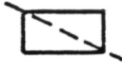
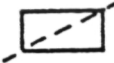
				HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
CONFIGURATION	X/D _E	T _j /T _o	M _j				
0 - 0 (BASELINE)	15	1	0.8	TAB282T	TAB281T	TAB287T	- - - -
	13	1	0.8	TAB302T	TAB293T	TAB145T	- - - -
	11	1	0.8	TAB134T	TAB133T	TAB143T	- - - -
	9	1	0.8	TAB147T	TAB146T	TAB165T	- - - -
	7	1	0.8	TAB130T	TAB129T	TAB144T	- - - -
	5	1	0.8	TAB128T	TAB127T	TAB329T	- - - -
	2	1	0.8	TAB126T	TAB125T	TAB137T	- - - -
	1	1	0.8	- - - -	TAB135T	TAB136T	- - - -
	5	2.3	0.8	TAB337T	TAB338T	TAB343T	- - - -
	7	2.3	0.8	TAB350T	TAB349T	- - - -	- - - -
	9	2.3	0.8	TAB332T	TAB331T	TAB346T	- - - -
	13	2.3	0.8	TAB356T	TAB355T	- - - -	- - - -
	9	1	1.15	TAB185T	TAB203T	- - - -	- - - -
	11	1	0.8	TAB336T	TAB367T	- - - -	- - - -
	13	1	0.8	TAB369T	TAB368T	- - - -	- - - -
BASELINE							
ROUND							

Figure 2.10 Baseline Test Conditions and Run Numbers

2.5.2 Mixing Modification

The majority of the runs that were made to evaluate the mixing modification produced by various tab configurations were made by operating the unheated jet at conditions corresponding to fully expanded jet exit Mach numbers of 0.8 and 1.15 and measuring the Mach number at $X/D_e = 9$. Conditions and run numbers for these tests are given in Figure 2.11.

After the initial evaluation runs at $X/D_e = 9$ were examined, additional runs were made for Configurations I-B and III-B for the unheated subsonic case at $X/D_e = 2, 5, 7, 11, 13$, and 15. These runs are identified in Figure 2.12.

The effect of mechanical tabs for the heated jet was examined at $T_j/T_o = 2.3$, $M_j = 0.8$, and $X/D_e = 5, 7, 9$, and 13. The nominal test conditions and corresponding run numbers are shown in Figure 2.13.

2.6 Test Procedures

The data acquisition process was automated so that the probability of human error was reduced as much as possible. Only the setting of plenum pressure and temperature was directly controlled by the operator; probe movement and transducer readings were under computer control by means of previously established command files.

The sequence of actions that constituted a run were as follows:

1. Find the center of the flow for the baseline configuration at the X/D_e location of the desired profile.

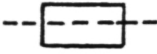
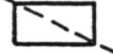
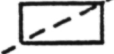
CONFIGURATION	X/D _E	T _j /T _o	M _j				
0 - 0							
(BASELINE)	9	1	0.8	TAB147T	TAB146T	TAB165T	TAB175T
I - A 	9	1	0.8	TAB157T	TAB158T	TAB168T	TAB176T
I - B 	9	1	0.8	TAB149T	TAB148T	TAB167T	TAB180T
III - A 	9	1	0.8	TAB161T	TAB162T	TAB169T	TAB177T
III - B 	9	1	0.8	TAB155T	TAB156T	TAB170T	TAB181T
II - A 	9	1	0.8	TAB151T	TAB152T	TAB171T	TAB178T
II - B 	9	1	0.8	TAB159T	TAB160T	TAB173T	TAB182T
IV - A 	9	1	0.8	TAB153T	TAB154T	TAB172T	TAB179T
IV - B 	9	1	0.8	TAB163T	TAB164T	TAB174T	TAB183T
VI - A 	9	1	0.8	TAB242T	TAB241T	TAB257T	TAB269T
VI - B 	9	1	0.8	TAB252T	TAB253T	TAB264T	TAB273T
VII - A 	9	1	0.8	TAB239T	TAB240T	TAB256T	TAB268T
VII - B 	9	1	0.8	TAB248T	TAB249T	TAB261T	TAB272T
V - C 	9	1	0.8	TAB275T	TAB276T	TAB260T	TAB274T
I - C 	9	1	0.8	TAB365T	TAB364T	- - - -	- - - -

Figure 2.11 (a) Mixing Modification Test Conditions
and Run Numbers - M_j = 0.8

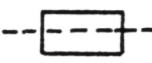
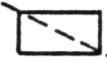
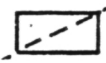
CONFIGURATION	X/D _E	T _j /T _o	M _j	HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
							
0 - 0							
(BASELINE)	9	1	1.15	TAB185T	TAB203T	TAB209T	TAB221T
I - A 	9	1	1.15	TAB187T	TAB204T	TAB210T	TAB223T
I - B	9	1	1.15	TAB196T	TAB195T	TAB213T	TAB226T
III - A 	9	1	1.15	TAB189T	TAB205T	TAB215T	TAB224T
III - B	9	1	1.15	TAB198T	TAB197T	TAB214T	TAB227T
II - A 	9	1	1.15	TAB191T	TAB206T	TAB220T	TAB228T
II - B	9	1	1.15	TAB200T	TAB199T	TAB219T	TAB231T
IV - A 	9	1	1.15	TAB193T	TAB207T	TAB217T	TAB230T
IV - B	9	1	1.15	TAB202T	TAB201T	TAB218T	TAB232T
VI - A 	9	1	1.15	TAB243T	TAB244T	TAB258T	TAB234T
VI - B	9	1	1.15	TAB251T	TAB250T	TAB263T	TAB236T
VII - A 	9	1	1.15	TAB238T	TAB237T	TAB255T	TAB233T
VII - B	9	1	1.15	TAB247T	TAB246T	TAB262T	TAB235T
V - C 	9	1	1.15	TAB278T	TAB277T	TAB259T	TAB266T

Figure 2.11 (b) Mixing Modification Test Conditions
and Run Numbers - M_j = 1.15

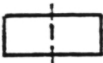
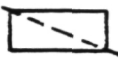
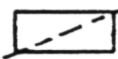
				HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
CONFIGURATION	X/D _E	T _j /T _o	M _j				
I - B 	15	1	0.8	TAB283T	TAB284T	TAB290T	- - - -
	13	1	0.8	TAB295T	TAB294T	TAB291T	- - - -
	11	1	0.8	TAB298T	TAB299T	TAB305T	- - - -
	9	1	0.8	TAB149T	TAB148T	TAB167T	TAB180T
	7	1	0.8	TAB324T	TAB325T	TAB306T	- - - -
	5	1	0.8	TAB321T	TAB320T	TAB308T	- - - -
	2	1	0.8	TAB316T	TAB317T	TAB313T	- - - -
III - B 	15	1	0.8	TAB286T	TAB285T	TAB289T	- - - -
	13	1	0.8	TAB296T	TAB297T	TAB292T	- - - -
	11	1	0.8	TAB301T	TAB300T	TAB304T	- - - -
	9	1	0.8	TAB155T	TAB156T	TAB170T	TAB181T
	7	1	0.8	TAB327T	TAB326T	TAB307T	- - - -
	5	1	0.8	TAB322T	TAB323T	TAB309T	- - - -
	2	1	0.8	TAB319T	TAB318T	TAB311T	- - - -

Figure 2.12 Test Conditions and Run Numbers for X/D_e Effects

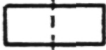
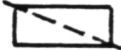
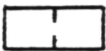
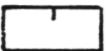
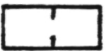
				HORIZONTAL	VERTICAL	DIAGONAL -14°
CONFIGURATION	X/D _E	T _j /T _o	M _j			
0 - 0 (BASELINE)	5	2.3	0.8	TAB337T	TAB338T	TAB343T
	7	2.3	0.8	TAB350T	TAB349T	- - - -
	9	2.3	0.8	TAB332T	TAB331T	TAB346T
	13	2.3	0.8	TAB356T	TAB355T	- - - -
I - B 	5	2.3	0.8	TAB340T	TAB339T	TAB344T
	7	2.3	0.8	TAB351T	TAB352T	- - - -
	9	2.3	0.8	TAB333T	TAB334T	TAB347T
	13	2.3	0.8	TAB354T	TAB353T	- - - -
III - B 	5	2.3	0.8	TAB341T	TAB342T	TAB345T
	9	2.3	0.8	TAB336T	TAB335T	TAB348T
I - C 	9	2.3	0.8	TAB359T	TAB360T	- - - -
	13	2.3	0.8	TAB357T	TAB358T	- - - -

Figure 2.13 Test Conditions and Run Numbers for the Heated Jet

2. Verify that the command file will execute the desired traverse of the probe.
3. Execute the command file to begin the test run.
4. Take a transducer zero reading before the test.
5. Set the plenum conditions for the test.
6. Initiate the traverse and data acquisition.
7. Measure pressures and temperatures.
8. Take a transducer zero reading after the test.
9. Identify the data set (file name and comments).
10. Reduce the data.

The location of the center of the jet is found by making short horizontal and vertical traverses in the vicinity of the jet center and adjusting the traverse zeroes to the profile peaks. The peaks are located by folding the left side of the profile over the right side and shifting the axis left or right to obtain the best match of the folded and unfolded profiles. For profiles that are not symmetrical, the region close to the peak was favored. Figure 2.14 shows a typical plot used to identify the center of the jet. In this example, the Z-axis had to be offset 3 mm downward ($\Delta Z = -3$) to achieve symmetry. This new position became the new Z-zero for the runs that followed at that X/D_e position.

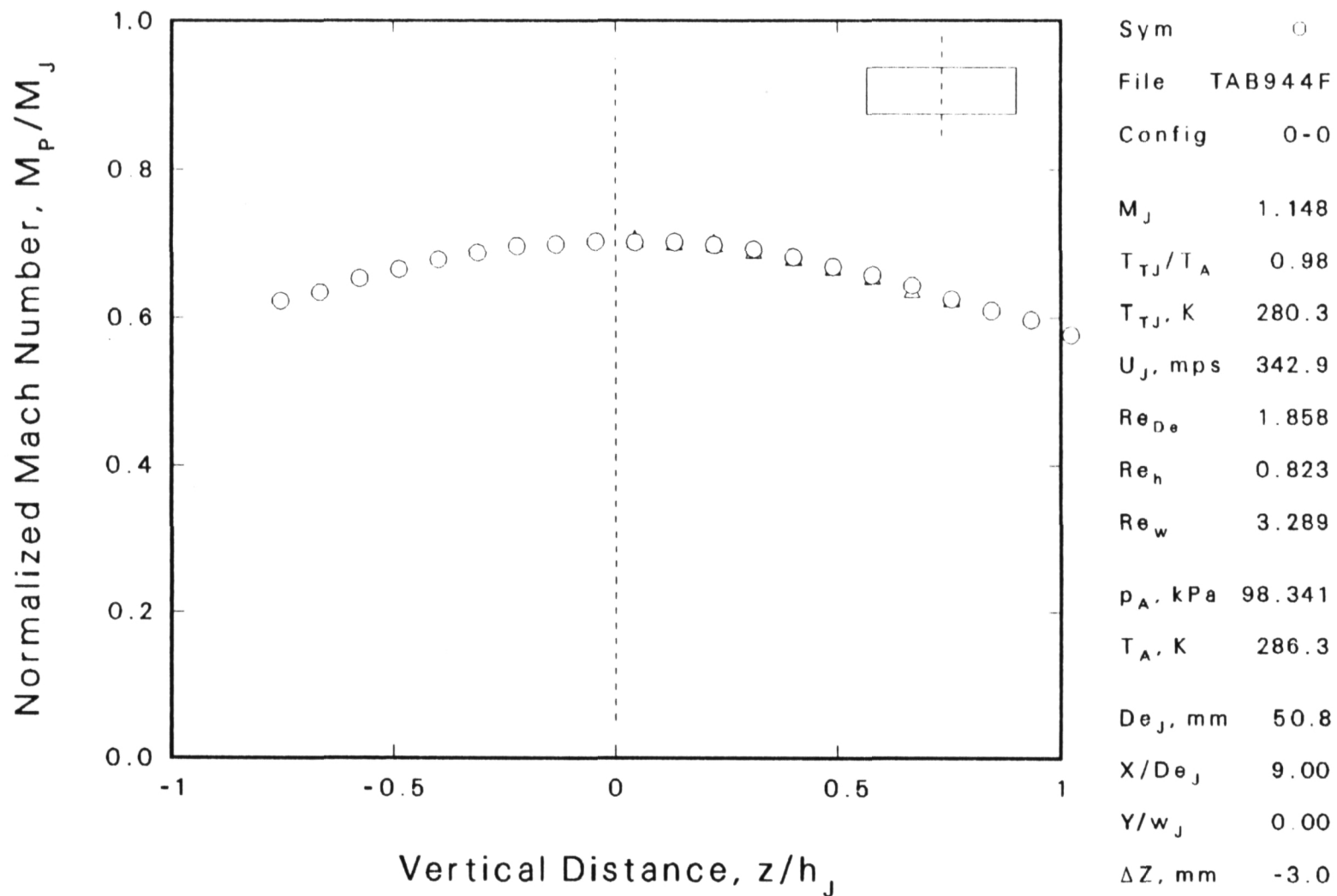


Figure 2.14 Sample Plot Showing Method of Locating Flow Centerline

3.0 ERRORS INTRODUCED INTO THE FLOW MEASUREMENTS BY PROBES

3.1 INTRODUCTION

The facility used in this program was originally designed for non-intrusive measurements through the use of a laser velocimeter (Reference 2).

Recently in a NASA program, Lepicovsky, et. al. (References 3, 4, and 5) made some jet velocity profiles measurements by a pitot probe which entered the flow from one side and penetrated to just beyond the jet center. In the current program, however, to determine the effects of mechanical tabs, it was necessary to obtain the complete velocity profiles right through the jet. Therefore, a substantial portion of the probe was immersed in the flow. Initial measurements made by a commercial pitot-static probe with a thermocouple, indicated that the velocity profiles were not symmetrical. Typical results are shown in Figure 3.1. This raised some questions that had to be resolved. The questions and related issues are discussed below.

The first question addressed was:

- (1) "Is the facility itself introducing an asymmetry in the velocity profiles?"

This question was resolved by making measurements in two different facilities and also by examining the flow with probes penetrating the flow from opposite sides. It was found that neither the facility nor the nozzles introduced any significant asymmetry into the jet velocity or temperature profiles.

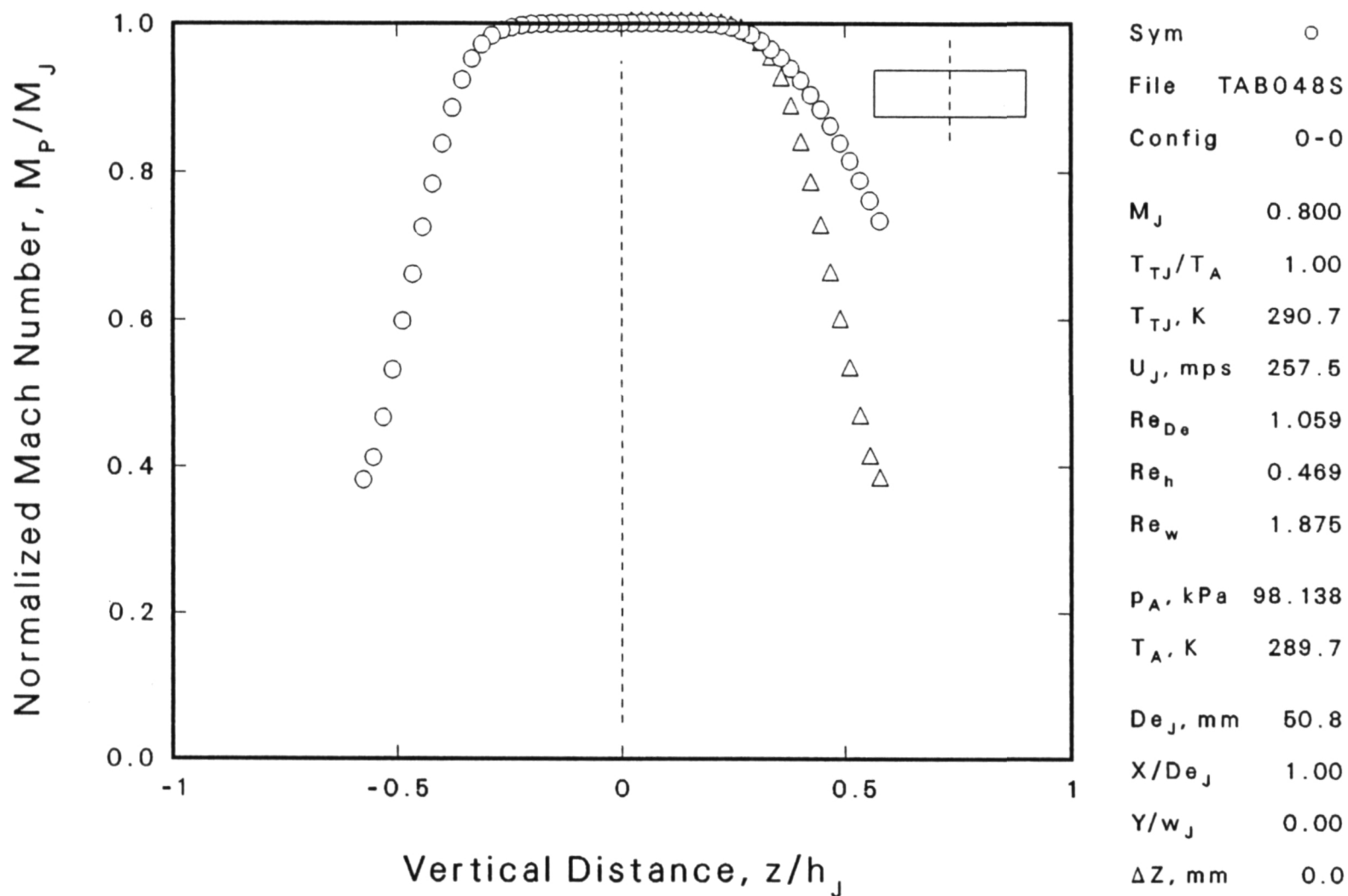


Figure 3.1 Skewed Mach Number Profile

The second question addressed was:

- (2) "Is the presence of the probe introducing some acoustic excitation in the jet flow? If so, is this effect a function of the size of the probe and the amount of immersion of the probe?"

It was found that large probes that penetrate the jet flow beyond the jet center may produce an acoustic excitation strong enough to modify the flow considerably. This will be discussed in subsequent sections.

3.2 BACKGROUND

The excitation of the jet by probes in the flow is related to the so called edgetone phenomenon first described by Powell (Reference 6). As shown in Figure 3.2, the pressure perturbation generated at a probe location travels upstream and excites an instability wave. This instability wave produces additional sound, when it reacts with the probe. The additional sound travels upstream and on reaching the nozzle lip, completes the feedback loop consisting of upstream travelling sound waves and downstream travelling instability waves, thus producing a self-sustained resonance.

This is clearly related to self-sustained acoustic excitation of the jet. There is ample evidence in the literature (Reference 2) that under certain conditions, the jet, under acoustic excitation, will have a broader plume resulting from the enhanced mixing brought about by the excited instability wave.

For impinging jets where the same phenomenon exists, Reference 7 indicates that this phenomenon is more likely to exist at jet Mach numbers in excess of 0.6 or so. In the present study at $M = 0.8$, it was indeed found that as the larger probes penetrated the flow beyond the jet

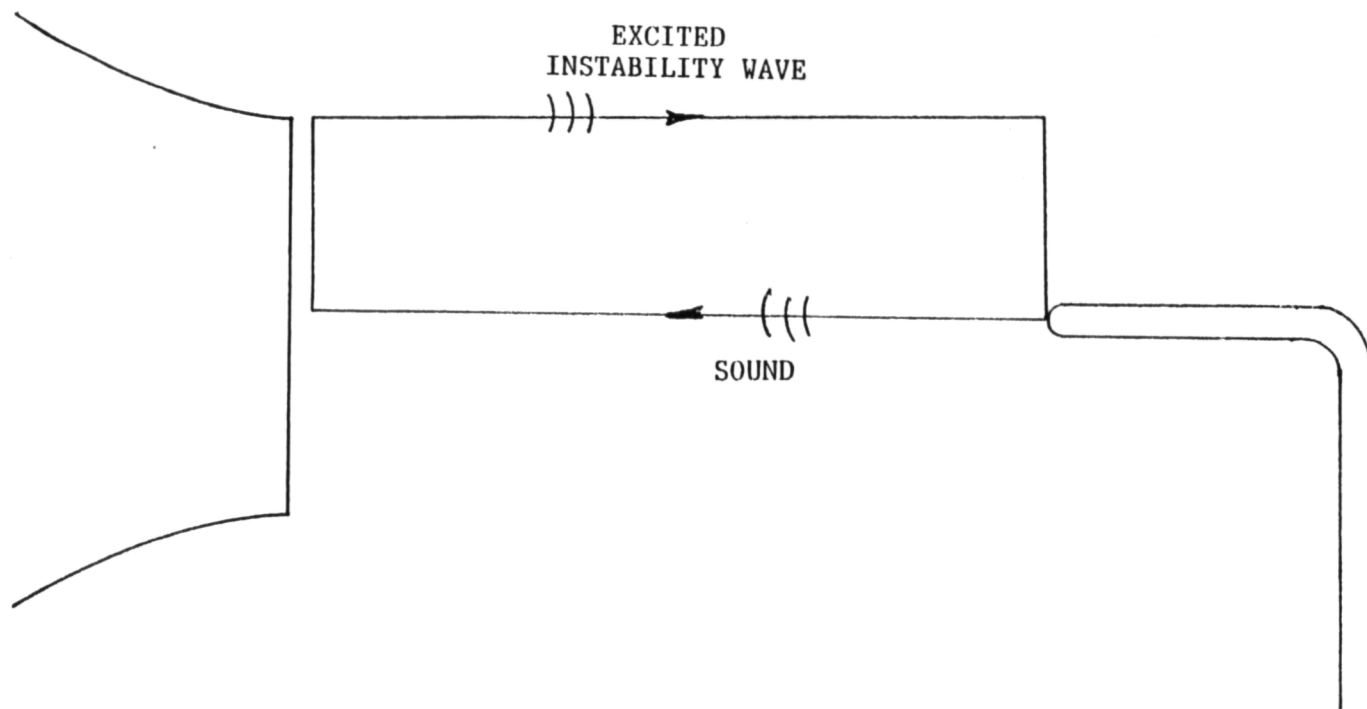


Figure 3.2 Acoustic Feedback Loop

center, high amplitude acoustic tones were heard and the jet shear layer was found to be affected considerably. It is likely, therefore, that in this case, the jet was significantly modified by the presence of the probe as indicated in Figure 3.3.

3.3 TEST SETUP

The tests were run in the Lockheed Jet Flow Facility which is described in more detail in Section 2. The nozzle was mounted on a 4-inch (10.16 cm) diameter extended plenum of the air supply system. The probe was mounted on a traverse frame that moved the probe in the streamwise, horizontal, and vertical directions. Approximately 4 inches (10.16 cm) of the probe extended beyond the probe holder.

Three different nozzles were used. Much of the work was done using a 2-inch (5.08 cm) diameter nozzle for which considerable reliable velocity data exists (References 3, 4, and 5). A 4-inch (10.16 cm) diameter nozzle (sharp-edged pipe) was used to evaluate the quality of the flow in the plenum. Finally, the intended test nozzle, a convergent rectangular nozzle of aspect ratio 4 and area equivalent to a 2-inch (5.08 cm) diameter circular nozzle was used. These nozzles are shown in Figure 3.4.

3.4 TEST CONDITIONS

Most of the tests were run at a Mach number of 0.8 and total temperature ratio of 1 or 1.6 at X-distances of 1, 3, or 9 equivalent nozzle diameters. However, some data were taken at a Mach number of 0.58 for comparison with previously obtained LV measurements for the same nozzle.

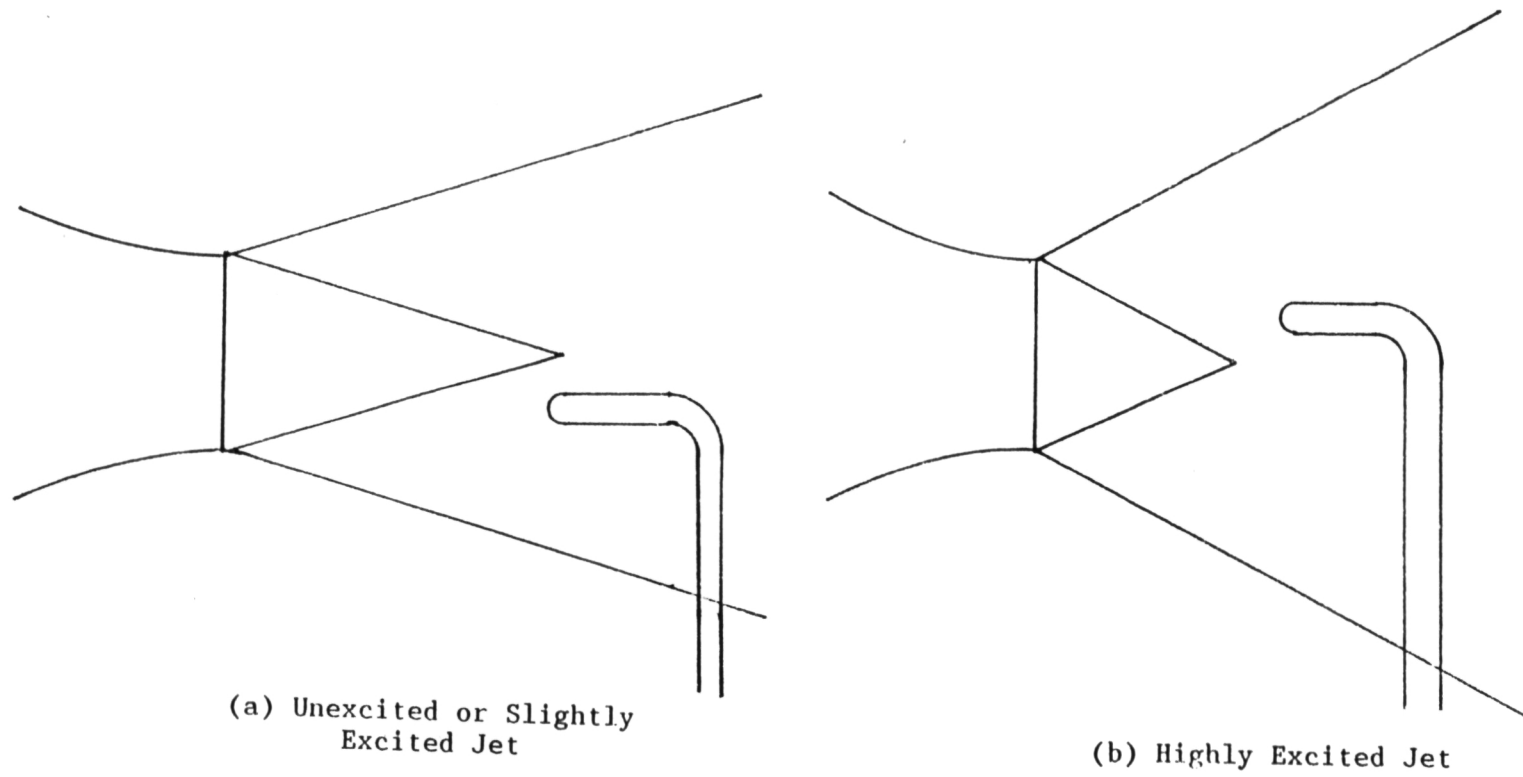
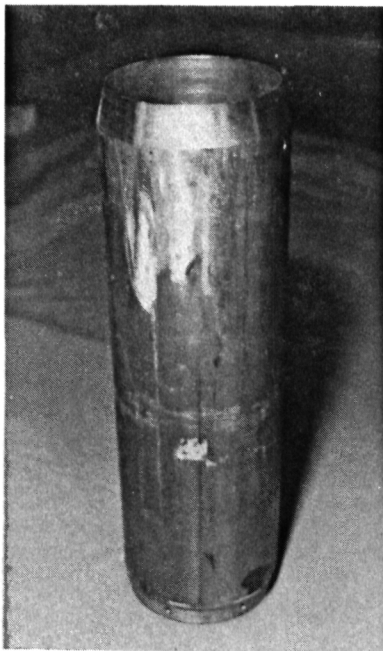


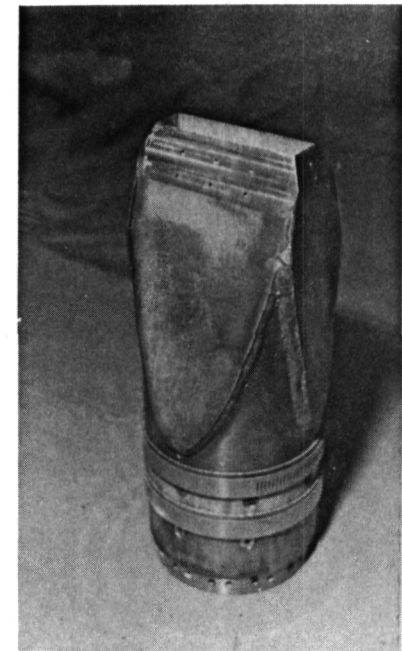
Figure 3.3 Illustration of Jet Excitation by Probes



FOUR-INCH
ROUND



TWO-INCH
CIRCULAR



RECTANGULAR

Figure 3.4 Test Nozzles

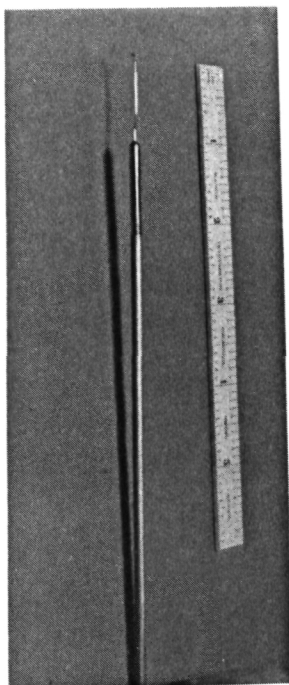
3.5 PROBE SIZES

The two probes used in this study were a Kiel probe with a miniature 1/16 inch diameter sensing head on a 1/8-inch diameter stem, United Sensor model USD-C-6, and a 0.020-inch diameter boundary layer probe on a 1/8-inch diameter stem, United Sensor model BA-.020-12-C-11-.650. A miniature thermocouple with a 0.020-inch OD sheath, Omega SCASS-020E-6, was added to the Kiel probe for temperature measurements. These probes are shown in Figure 3.5. Except where noted, the Kiel probe with the thermocouple was used to obtain the data of this section.

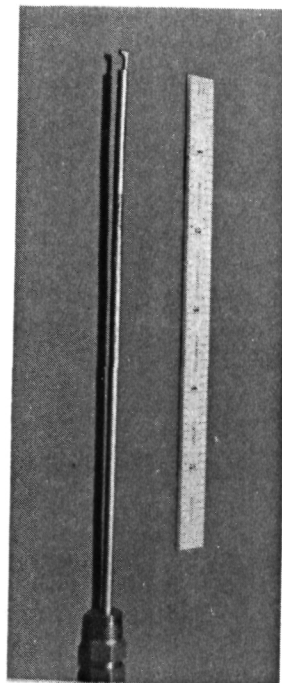
3.6 MEASUREMENT PHILOSOPHY

The Kiel probe was selected because it is insensitive to flow direction changes over a wide range of pitch and yaw. This is advantageous in highly turbulent flows such as those in the near wake of the tabs and in the shear layer of the jet. The basic plan was to compare its measurements with those obtained by less intrusive means. This involved comparison of the Kiel probe measurements with those made using a thin boundary layer probe and a laser velocimeter.

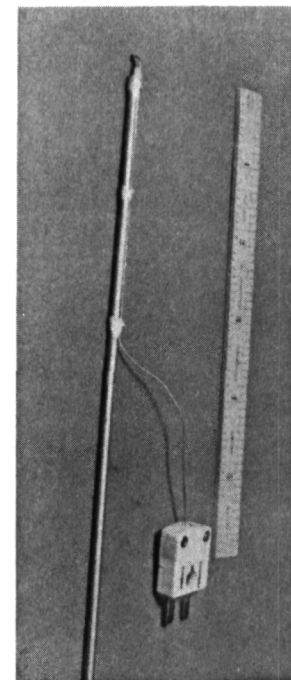
The majority of measurements were made using a 2-inch (5.08 cm) diameter conical nozzle whose characteristics are known. The first task was to determine whether or not the facility produced some asymmetry in the flow that it provided to the nozzle inlet. Another task was to determine whether or not the new nozzle produced clean and symmetrical velocity and temperature profiles. After that, the effects of the probe itself could be evaluated.



BOUNDARY
LAYER



KIEL



KIEL WITH
THERMOCOUPLE

Figure 3.5 Test Probes

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

3.7 RESULTS

3.7.1 EXAMINATION FOR POSSIBLE FACILITY EFFECTS

Velocity profiles were measured vertically across the plume of a 4-inch (10.16 cm) diameter nozzle at $X/D=1$ to assess the uniformity of the flow in the 4-inch (10.16 cm) plenum that feeds the test nozzles in the Jet Flow Facility. As shown in Figure 3.6, the pattern is flat in the core region of the jet and reasonably symmetrical. The points shown as circles on the left side of the jet axis have been transposed to the right side and plotted as triangles for the purpose of illustrating symmetry. The slight asymmetry that is seen in the profile is more likely to show the effects of probe immersion than of actual flow asymmetry as shown later.

Next, a 2-inch (5.08 cm) diameter convergent nozzle of known characteristics was mounted on the 4-inch (10.16 cm) plenum section and evaluated. Horizontal velocity and temperature profiles were measured at $X/D=3$, the location at which mixing layer turbulence levels typically peak. Any effects of non-uniform plenum velocity profiles should be evident by then. As shown in Figure 3.7, the Mach number profile displays excellent symmetry, and the temperature profile is, within a reasonable scatter range, acceptably symmetrical.

3.7.2 EXAMINATION OF MEASURED TEMPERATURE PROFILES

A comparison of the temperature profiles measured by a commercial total temperature probe and the modified Kiel probe show excellent agreement in profile shape in Figure 3.8. The peak normalized levels are not identically unity because temperature corrections had not been introduced into the data reduction program at the time of these measurements. The flatness of core flow and the agreement in profile shapes are the

important points of this figure. They show that the temperature profile that is supplied by the burner system to the nozzle is uniform.

The next step was to verify that the installation of the sheathed thermocouple had no adverse effects on the performance of the Kiel probe. The velocity profiles shown in Figure 3.9 are essentially identical for the probe with and without the thermocouple. Therefore, the installation of the thermocouple did not affect the velocity sensing capability of the probe.

Having established that the thermocouple installed on the Kiel probe did not interfere with the velocity measurements and did measure temperatures correctly, measurements were made across the 2-inch (5.08 cm) diameter jet from below and above the jet. The profiles were found to be asymmetrical, but they appeared to be mirror images of each other. The profile measured with the probe approaching from above was reversed to facilitate the comparison. As shown in Figure 3.10, the profiles are good mirror images of each other. This is consistent with the conclusion that neither the facility nor the circular nozzle introduces any significant asymmetry into the jet velocity or temperature profiles.

3.7.3 EXAMINATION OF MEASURED VELOCITY PROFILES

The vertical velocity profile at $X/D=3$ measured by the Kiel probe is much wider than that measured by the boundary layer probe as shown in Figure 3.11. Because an audible tone was heard during this Kiel probe run, it is believed that instabilities in the shear layer have been excited by the probe itself. The fact that the leading edge of the profiles have the same shape up to the potential core suggests that the Kiel probe does not significantly affect the flow until a substantial portion of the probe is immersed in the flow. The boundary layer probe, being much smaller, produced little, if any, affect on the flow profile on either side of the jet centerline.

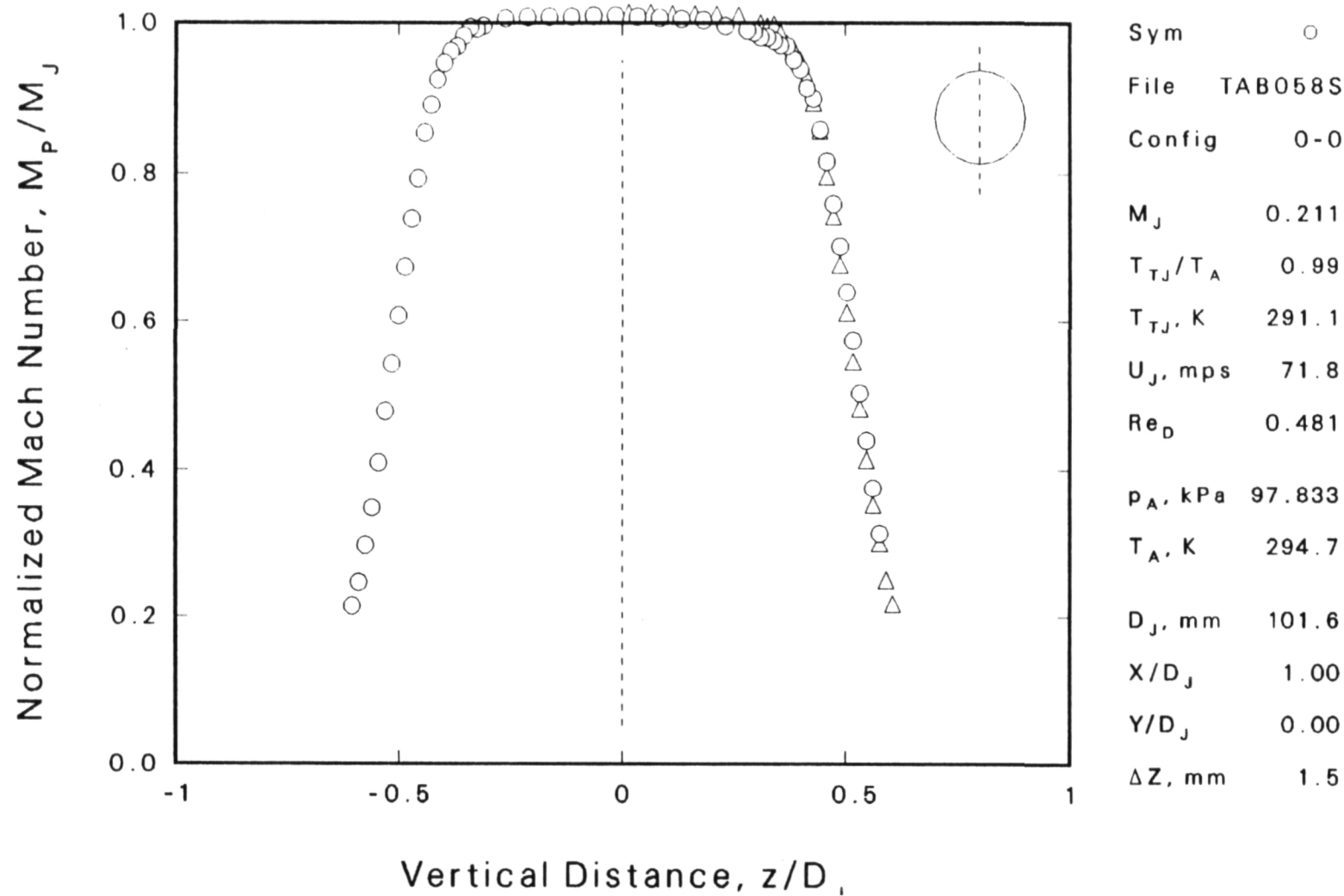


Figure 3.6 Profile Symmetry for Four-Inch Diameter Pipe

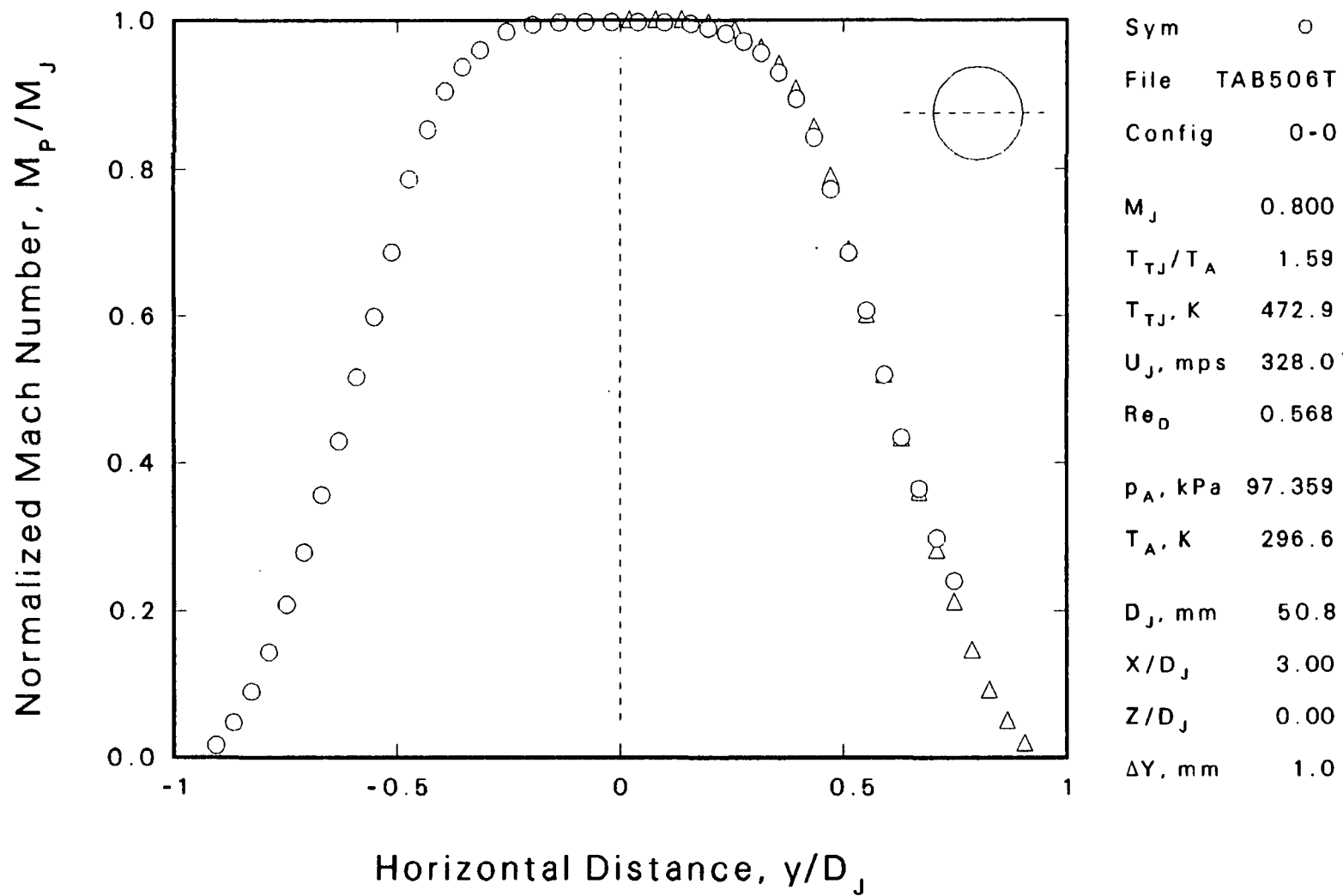


Figure 3.7 (a) Profile Symmetry for Two-Inch Nozzle Mach Numbers

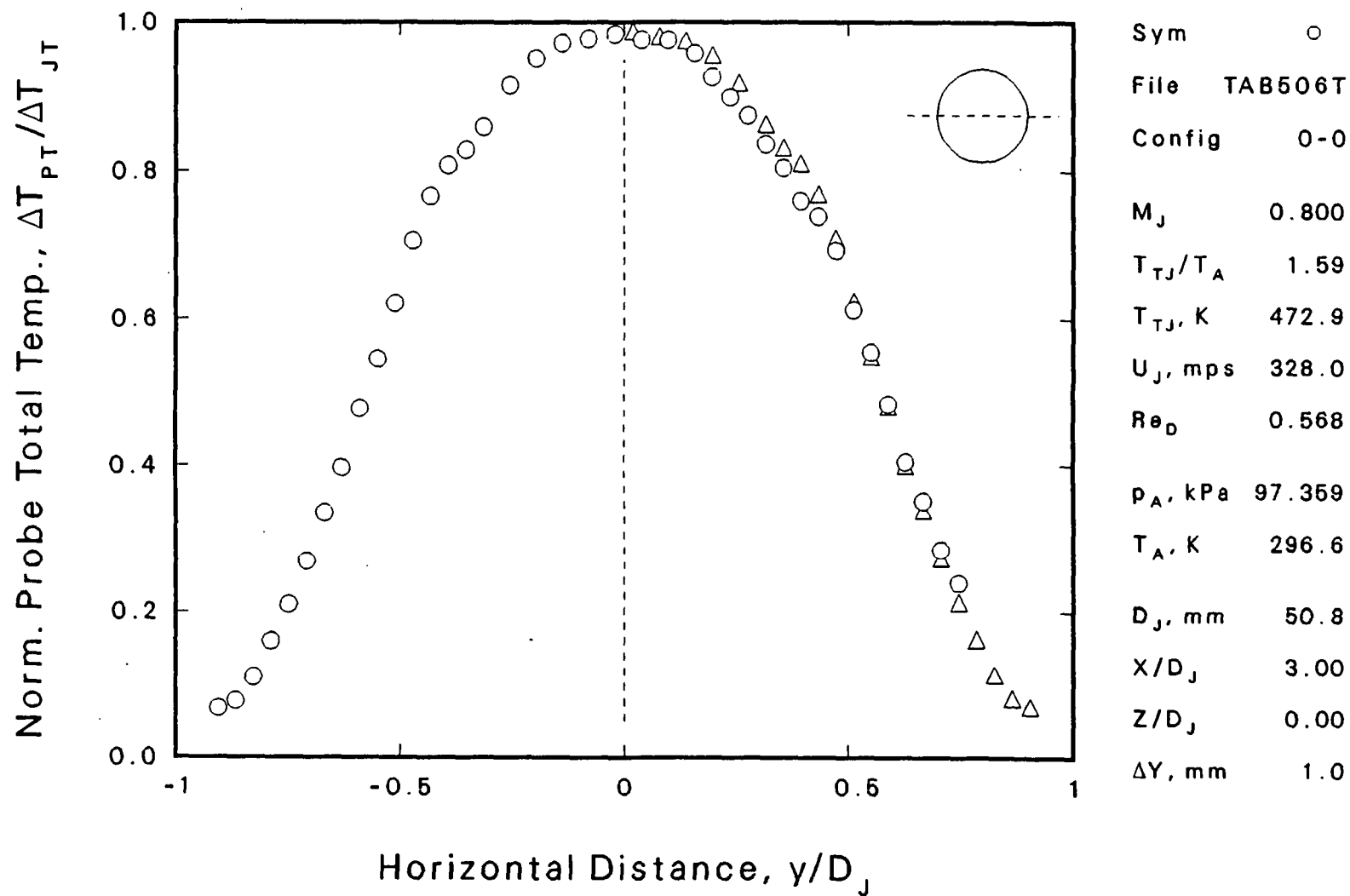
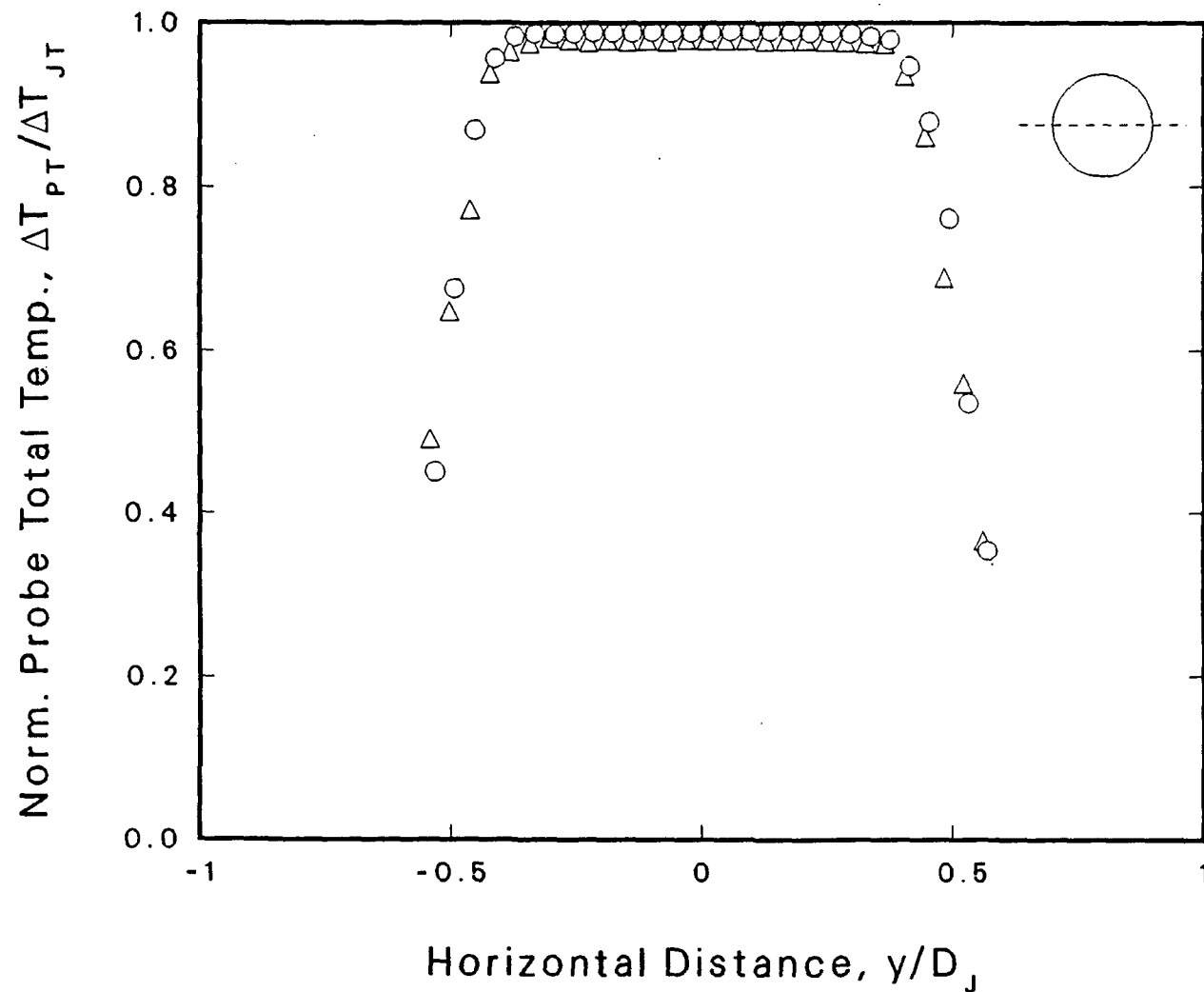


Figure 3.7 (b) Profile Symmetry for Two-inch Nozzle Temperature



Sym	○	△
File	TAB513T	TAB515T
Config	0-0	0-0
M_J	0.800	0.801
T_{TJ}/T_A	1.60	1.61
T_{TJ}, K	466.2	471.7
U_J, mps	325.7	327.9
Re_D	0.583	0.574
p_A, kPa	98.205	97.901
T_A, K	290.8	293.8
D_J, mm	50.8	50.8
X/D_J	1.00	1.00
Z/D_J	0.00	0.00
$\Delta Y, mm$	-1.0	-0.5
	Centro	Kiel

Figure 3.8 Comparison of Temperature Profiles Measured by Centro and Kiel Probes

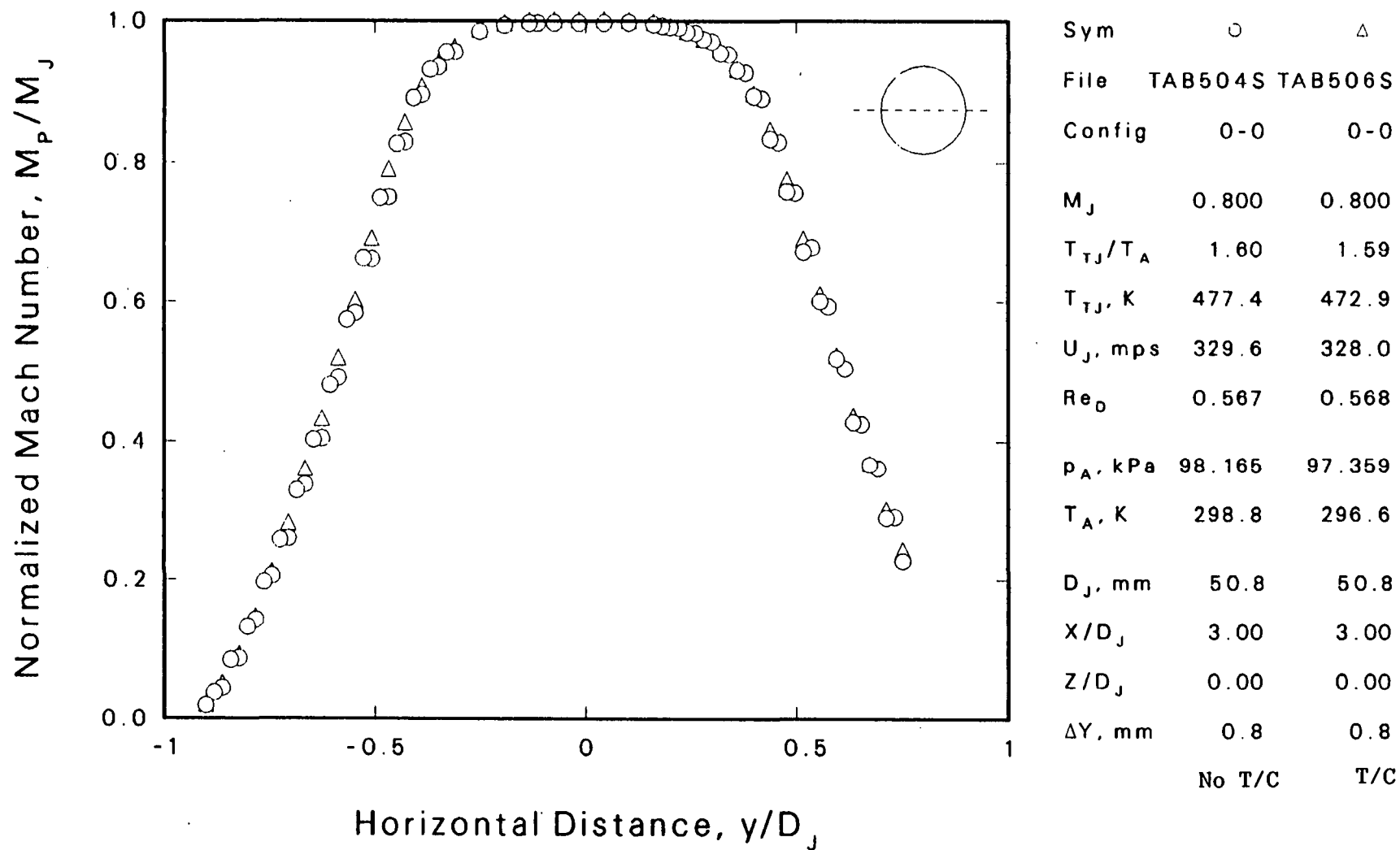
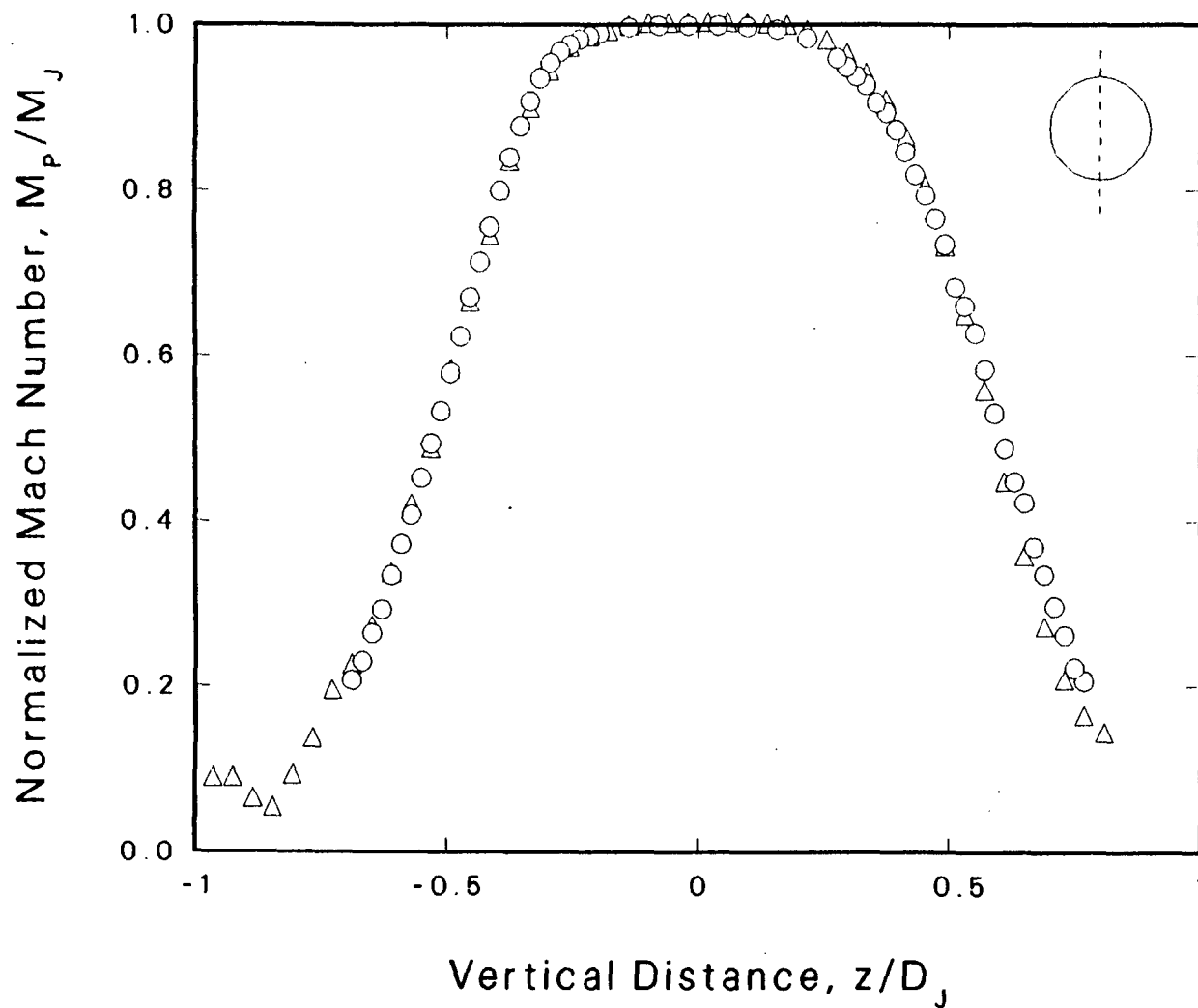


Figure 3.9 Effect of Thermocouple Installation on Kiel Probe Mach Number Measurements



Sym	○	△
File	TAB505S	TAB523S
Config	0-0	0-0
M_J	0.800	0.800
T_{TJ}/T_A	1.60	1.61
T_{TJ} , K	474.8	463.6
U_J , mps	328.6	324.8
Re_D	0.586	0.586
p_A , kPa	97.460	97.934
T_A , K	295.9	288.5
D_J , mm	50.8	50.8
X/D_J	3.00	3.00
Y/D_J	0.00	0.00
ΔZ , mm	-5.0	4.0
	From Below	From Above

Figure 3.10 Kiel Probe Traverses from Below and Above the Nozzle

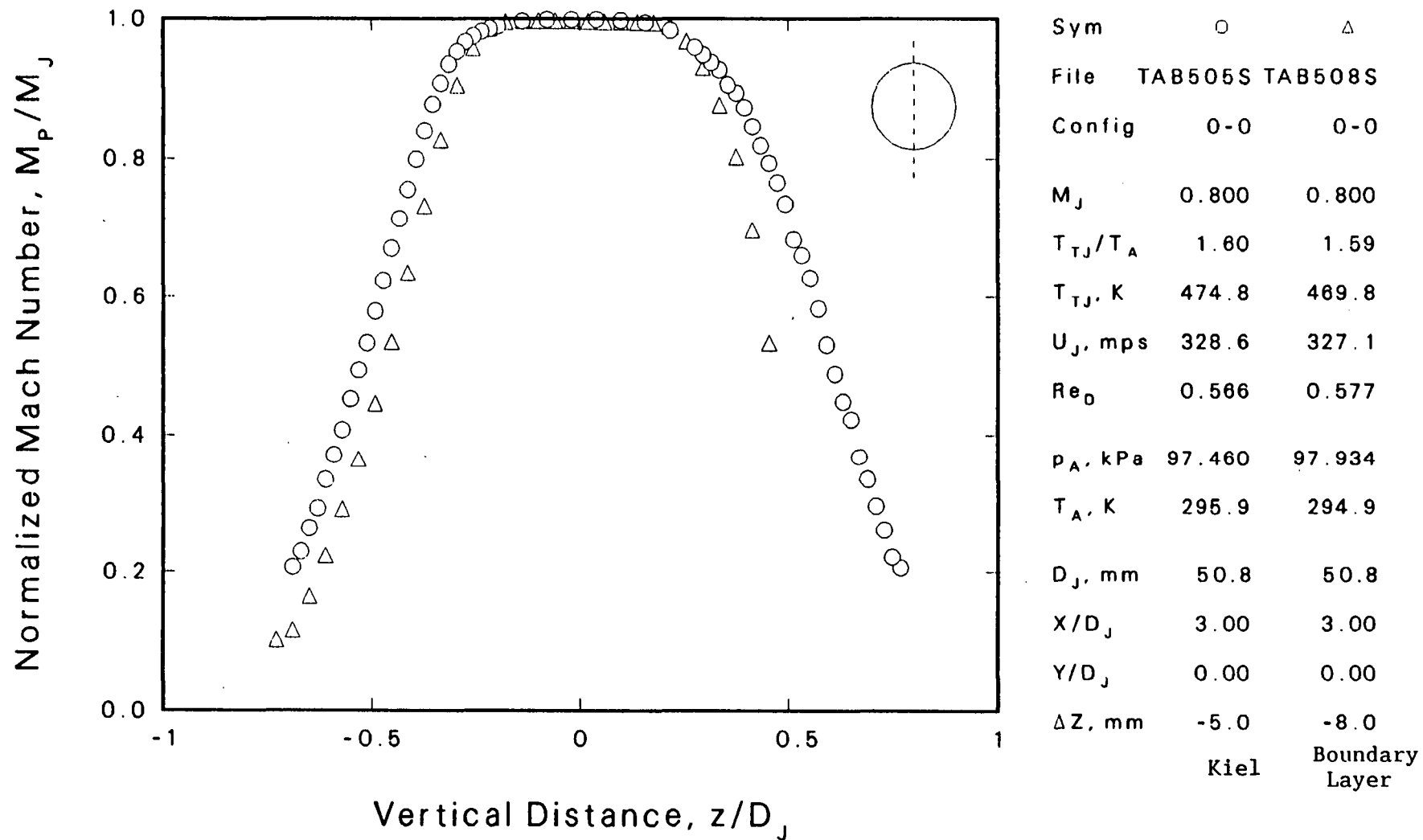


Figure 3.11 Comparison of Profiles Measured by Kiel and Boundary Layer Probes

In the absence of audible tones, the horizontal profile measured by the Kiel probe agrees well with those measured by the boundary layer probe as shown in Figure 3.12. The absence of audible tones suggests that the flow had not been excited by either probe. In that case, no difference would be expected between the measurements.

Velocity profiles measured by Kiel Probes across the circular nozzle from above and below are essentially mirror images of each other as shown in Figure 3.13 where the profile "from above" is plotted after reflection across the jet axis. The profile is steeper on the side from which the probe is entering the flow and broader on the opposite side. This indicates that there is a threshold in the amount of flow interference that is required before the flow is noticeably modified.

3.8 COMPARISON WITH LV DATA

Velocity profiles measured by the boundary-layer probe and by the LV at $X/D=3$ and $M_j = 0.58$ agree very well as shown in Figure 3.14. This supports the idea that the boundary-layer probe is small enough so that it does not appreciably affect the flow that it is trying to measure.

Vertical traverses across the rectangular jet typically are asymmetric with a steeper slope on the side from which the probe enters the flow and a broader profile on the opposite side. Because it is conceivable that such behavior with the rectangular nozzle could be due, at least in part, to some fault of the nozzle, profiles were measured with the nozzle in its normal orientation and inverted. The profiles fall directly on top of each other as shown in Figure 3.15. Therefore, the nozzle itself cannot be the cause of the profile asymmetry. Probe effects on the flow appear to be the cause of the profile broadening that is measured on the side opposite the place where the probe entered the flow.

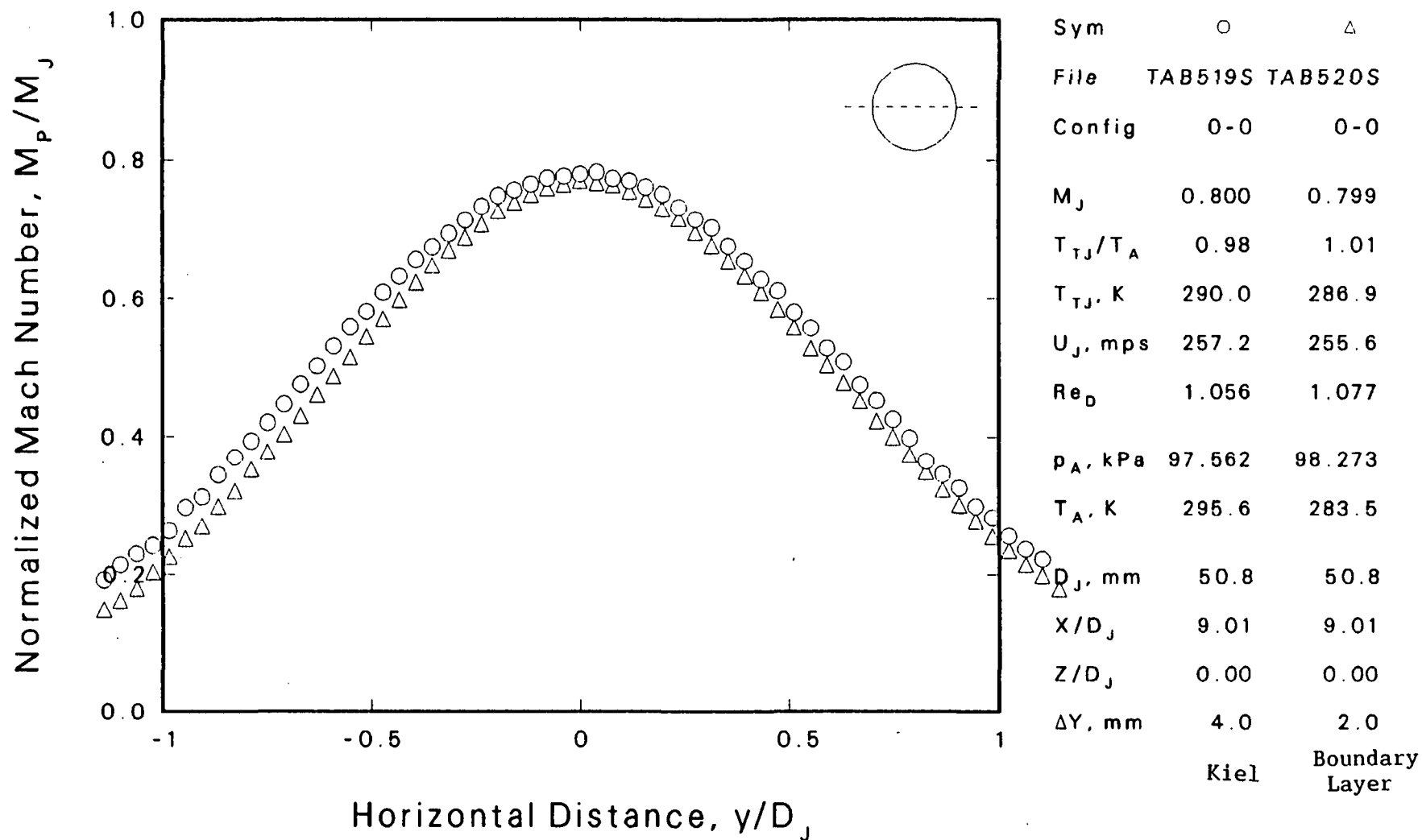
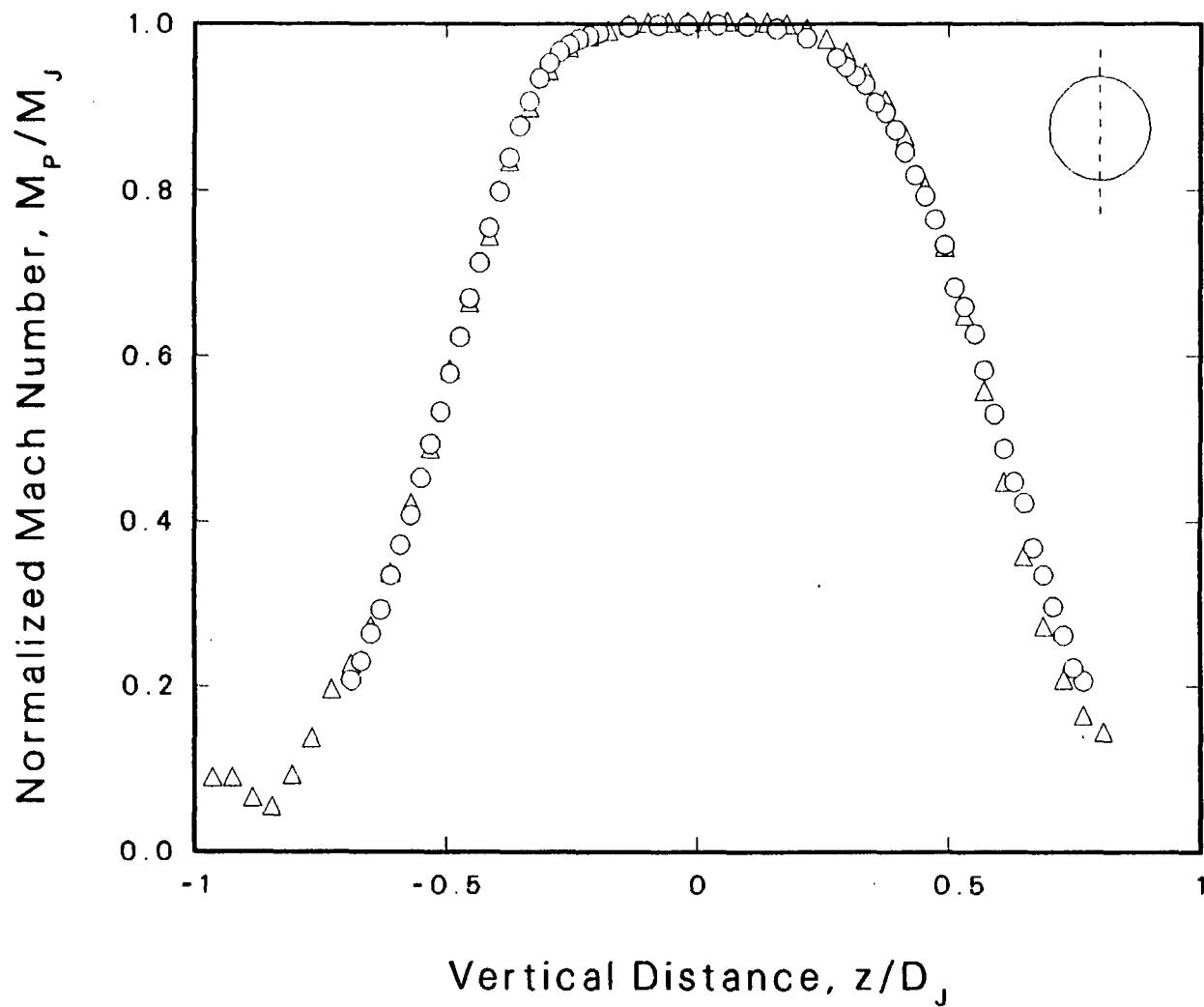
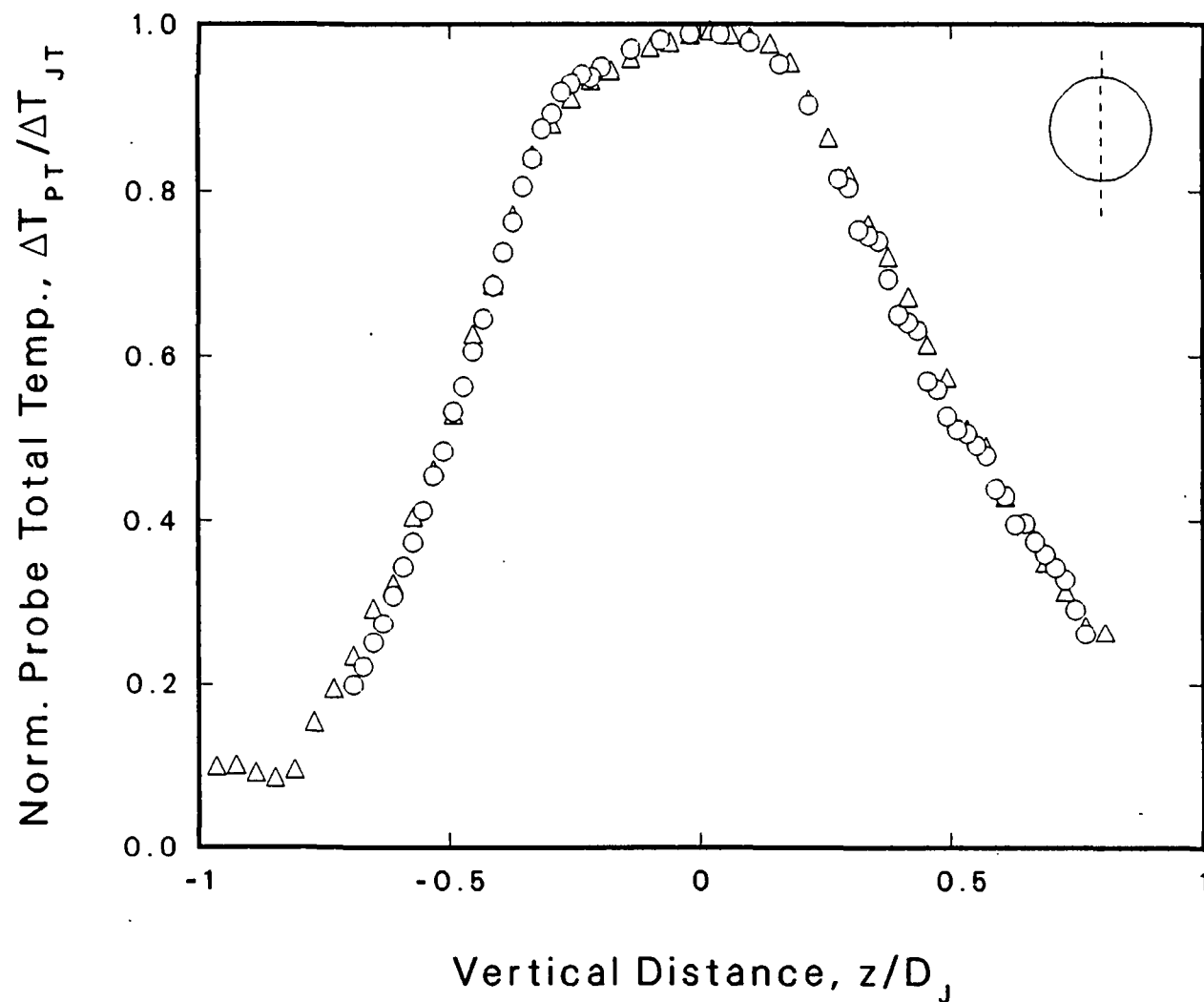


Figure 3.12 Comparison of Profiles Measured by the Kiel and Boundary Layer Probes in the Absence of Tones



Sym	O	Δ
File	TAB505T	TAB523T
Config	0-0	0-0
M_j	0.800	0.800
T_{TJ}/T_A	1.60	1.61
T_{TJ}, K	474.8	463.6
U_j, mps	328.6	324.8
Re_D	0.586	0.586
p_A, kPa	97.460	97.934
T_A, K	295.9	288.5
D_j, mm	50.8	50.8
X/D_j	3.00	3.00
Y/D_j	0.00	0.00
$\Delta Z, mm$	-5.0	4.0
	From Below	From Above

Figure 3.13 (a) Comparison of Profiles Measured by Kiel Probes from Below and Above, Mach Number



Sym	○	△
File	TAB505T	TAB523T
Config	0-0	0-0
M_j	0.800	0.800
T_{TJ}/T_A	1.60	1.61
T_{TJ}, K	474.8	463.6
U_j, mps	328.6	324.8
Re_D	0.566	0.586
p_A, kPa	97.460	97.934
T_A, K	295.9	288.5
D_j, mm	50.8	50.8
X/D_j	3.00	3.00
Y/D_j	0.00	0.00
$\Delta Z, mm$	-5.0	4.0
	From Below	From Above

Figure 3.13 (b) Comparison of Profiles Measured by Kiel Probes from Below and Above, Temperature

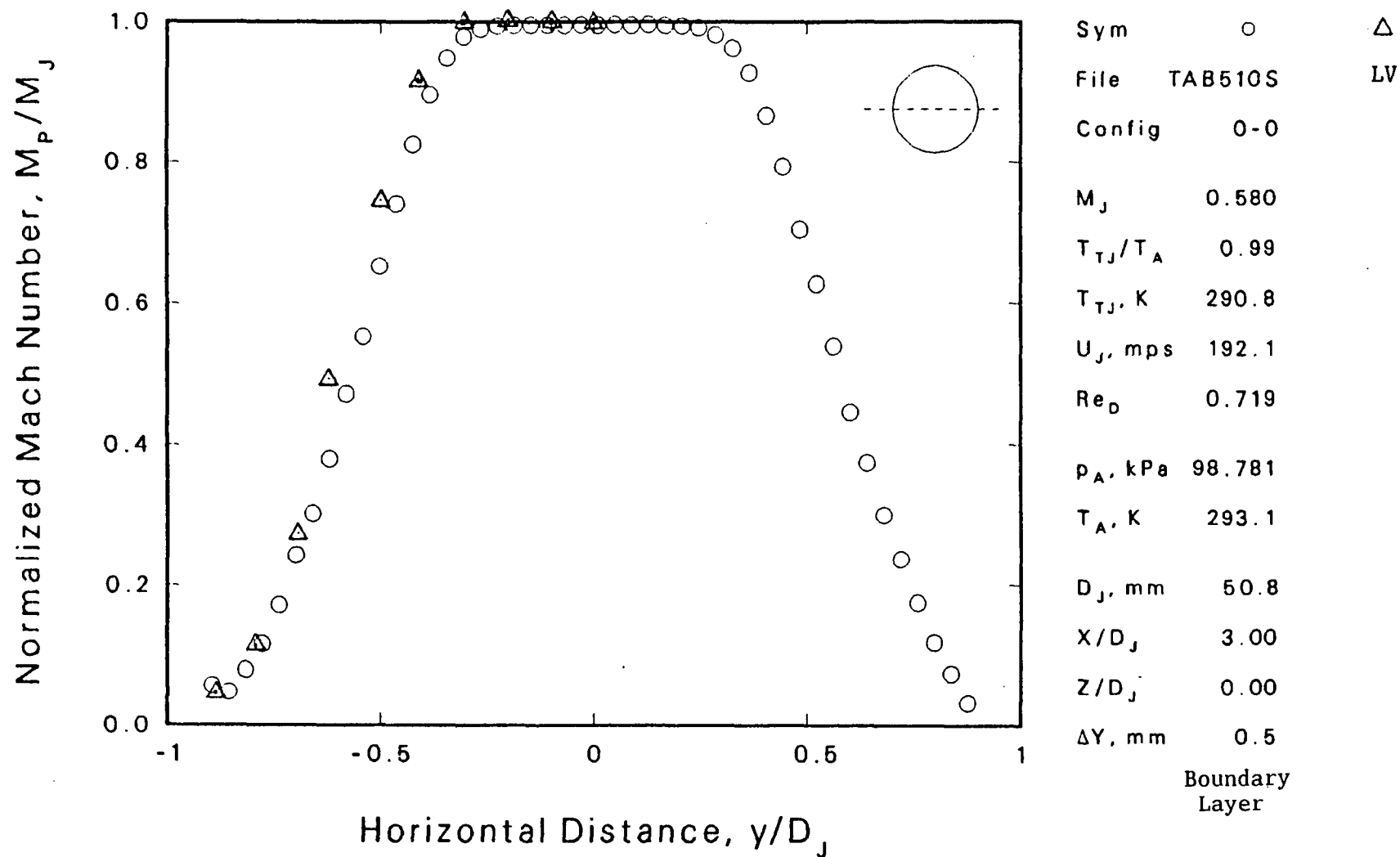
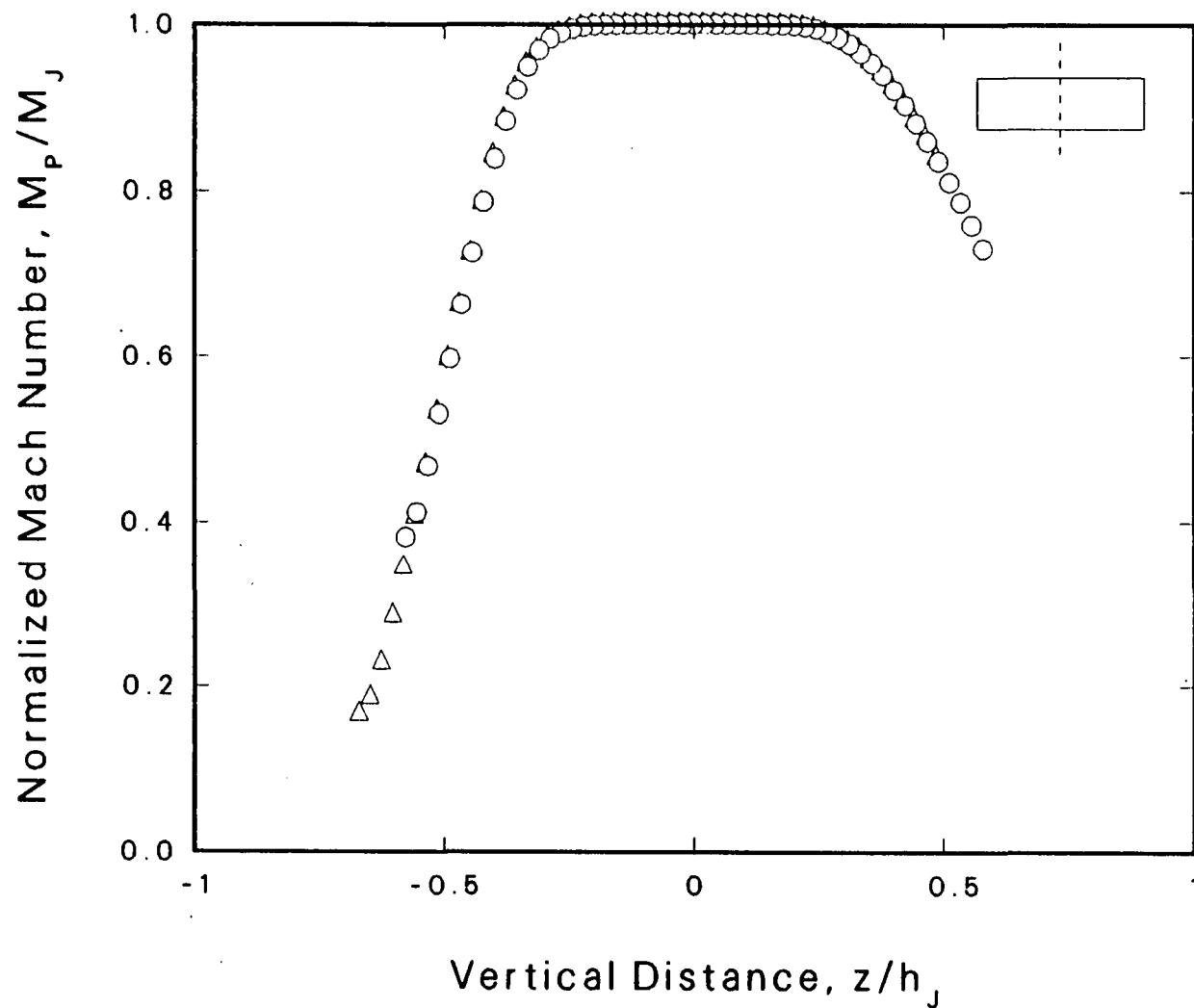


Figure 3.14 Comparison of Profiles Measured by Boundary Layer Probe and by LV



Sym	O	Δ
File	tab049s	tab053s
Config	0-0	0-0
M_j	0.800	0.800
T_{TJ}/T_A	0.99	0.98
T_{TJ} , K	291.3	292.7
U_j , mps	257.9	258.5
Re_{D_o}	1.057	1.047
Re_h	0.468	0.464
Re_w	1.871	1.854
p_A , kPa	98.171	97.867
T_A , K	294.2	300.0
De_j , mm	50.8	50.8
X/De_j	1.00	1.00
Y/w_j	0.00	0.00
ΔZ , mm	0.0	2.1

Figure 3.15 Effect of Nozzle Inversion on Measured Mach Number Profile

Because the boundary layer probe agrees with previous LV data, this suggests that the Kiel probe produces accurate results until the threshold level of probe insertion is reached.

3.9 DISCUSSION

Intrusive measurements have long been known to alter the flow that they are intended to measure. The measurements are made more accurate by making the probes less intrusive, which usually means smaller. That process is limited, however, by the requirement for adequate strength in the probe, and the required strength increases rapidly with flow velocity. Therefore, some compromise between size and strength is required. A Kiel probe with a miniature (1/16-inch diameter) head to which a miniature thermocouple was added was found to be adequate for the present program.

Broadening of vertical profiles made through the flow of an AR=4 nozzle near its exit clearly show that the character of the flow can be changed significantly when a probe is deeply immersed in it. It was not the intent of this program to determine the detailed criteria, such as probe size and immersion depth as functions of Mach number, that result in significant modification of the flow at the measurement location. However, a comparison of velocity profiles for the 2-inch (5.08 cm) diameter circular nozzle obtained using the Kiel probe traversing upward and using the LV does show that the Kiel probe did not significantly affect the measurement on the lower (probe entrance) side of the flow.

3.10 CONCLUSIONS

1. The 1/8-inch diameter stem of the Kiel and boundary layer probes is sufficiently large to modify the jet from a 2-inch (5.08 cm) diameter jet or the equivalent area aspect ratio 4 rectangular nozzle when enough stem is exposed to flow. The amount of stem exposure required to modify the flow was not determined.
2. The pressure measuring performance of the Kiel probe was unaffected by the installation of the sheathed thermocouple.
3. The modified Kiel probe produced the same total temperature profile as did the shielded and vented commercial total temperature probe.
4. For the subsonic conditions of this program, the modified Kiel probe is adequate for both temperature and pressure measurements, provided that it is not inserted more than halfway through the jet.
5. A systematic investigation of the parameters of jet modification by probes is needed to provide guidance in the selection of probes for the measurement of profiles in jets. Important variables might include such things as jet exit Mach number, local Mach number, temperature, probe size, probe immersion, probe head shape, and probe stem shape.

4.0 MEAN FLOW MEASUREMENTS IN COLD AND HEATED RECTANGULAR JETS

4.1 Introduction

A considerable amount of mean flow data was acquired for the rectangular jet without tabs as the baseline for measuring the effect of the tabs. These data are presented in this section in the form of selected jet Mach numbers and temperature profiles at various axial locations, X/D_e .

4.2 Background

Rectangular jets are important in the aerospace community due to their use in vectored thrust applications on aircraft. Also, the use of rectangular jets increases the mixing of the jet plume with the surroundings and, hence, decreases jet detection. However, to date, data from only a few sources are available documenting the mean flow field and the classical turbulence properties of lower aspect ratio rectangular jets.

Hsia, et. al. ⁸, Krothapalli, et. al. ⁹, Marsters ^{10, 11}, Sfeir ¹², Pani and Dash ¹³, and Sforza ^{14, 15}, have performed experimental studies of rectangular jets. The majority of these studies were for aspect ratios greater than 10 and were for jets with heights on the order of 5 mm. The jet height (h) is the shorter dimension of the rectangular jet. Due to the small height of the jet and the size of the measurement device (2 - 5 mm in diameter for both hot-wire and pressure probes), considerable probe interference occurs in these measurements.

Hsia, et. al. ⁸, Krothapalli, et. al. ⁹, Marsters ^{10, 11}, and Sfeir ¹², measured the axial mean velocity (U), the axial turbulence intensity (u'), the turbulence intensity normal to the major axis (v'), and their

product ($u'v'$). Krothapalli, et. al. ⁹ and Marsters ¹⁰ included the measurement of the other turbulence intensity which was normal to the minor axis (w') and its correlation with u' ($u'w'$). Marsters ¹⁰, who used jets with the largest slot heights (12.8 to 17 mm), encountered difficulties in using a crossed hot-wire probe in the small jets. Determining the local mean velocity direction was virtually impossible in the highly sheared flow. Each of the wires, displaced only slightly, sensed different mean velocities, and yawing the probe to get equal outputs led to incorrect results.

Due to the problems encountered with the spatial resolution of hot-wire and pressure probes and to the fact that the crossed hot-wire probes cannot measure the entire Reynolds stress tensor nor the mean velocity vector, there is no complete set of data available documenting the flow field of rectangular jets. In the aspect ratio range of 2:1 to 4:1, which is the aspect ratio range being considered for application to aircraft, there has been only one study using crossed hot-wire probes by Marsters ¹¹.

Based upon these studies, it appears that rectangular jets exchange the orientation of the major and minor axes at least once as the flow progresses downstream. The proposed mechanism for this is the presence of longitudinal vortical structures at the corners of the jet. However, in order to completely understand this highly three dimensional flow, measurements with high spatial resolution of the mean flow field of the entire velocity vector and the complete Reynolds stress tensor are needed. The measurement of all three components of the mean velocity will identify and quantify the vortical structures present and provide the information necessary for the basic understanding of the jet's development. The Reynolds stress tensor measurements will provide valuable information about the turbulent structure of the jet. This type of data can only be obtained using a three dimensional laser anemometer system and has recently been acquired by Morrison, et. al. ¹⁶. Reference 16 presents complete mean velocity and Reynolds stress tensor

measurements along the major and minor axis planes for a 2:1 aspect ratio jet. These measurements indicate that the jet spreads more rapidly along the minor axis resulting in a larger normal velocity component in the minor axis direction. The turbulence intensities attain approximately the same value in the same regions on both planes indicating isotropic turbulence.

Based upon these previous studies, it appears that the flow field of an incompressible rectangular jet can be characterized by the presence of three distinct regions as defined by the decay of the mean axial velocity along the centerline of the jet U_c . These three regions are classified as follows: a potential core region, where U_c is constant; a two-dimensional type region, where U_c decays similar to a self-preserved two-dimensional jet; and an axisymmetric type region, where U_c decays at the same rate as a self-preserved axisymmetric jet. In the two-dimensional type region, saddle shape mean velocity profiles were observed in the plane containing the long dimension of the nozzle.

In light of the past experimental observations, the characteristics of a rectangular jet are expected to depend upon the following parameters:

- o aspect ratio of the nozzle
- o inlet geometry of the nozzle
- o Mach number at the nozzle exit
- o Reynolds number at the nozzle exit
- o type of exit velocity profile
- o type of boundary layer at the nozzle exit
- o magnitude of the turbulence intensity at the exit plane of the nozzle
- o conditions of the ambient medium into which the jet is issuing

4.3 Test Conditions

Mean flow measurements were made for the baseline nozzle for both cold and heated subsonic flow and for cold supersonic flow. For cold subsonic conditions, velocity profiles were acquired at $X/D_e = 2, 5, 7, 9, 11, 13,$ and 15 for a jet exit Mach number of 0.8 . For heated subsonic conditions, data were obtained at $X/D_e = 5, 7, 9,$ and 13 for the same jet exit Mach number. The heated tests were run with the ratio of plenum total temperature to ambient static jet temperature of 2.3 . Supersonic jet measurements were made at $X/D_e = 9$ for a fully-expanded jet-exit Mach number of 1.15 . These conditions and the corresponding run numbers are shown in Figure 4.1.

Velocity profiles (and temperature profiles for the heated case) were measured along the vertical and horizontal axes of the jet and along the -14° diagonal. As noted in Table 4.1, the $+14^\circ$ diagonal is included, and the diagonals are not included for the heated jet at $X/D_e = 7$ and 13 .

4.4 Measurement Philosophy

The test data acquisition system is automated so that the probe positioning and pressure and temperature measuring processes are as reproducible as possible. The test conditions of pressure and temperature are manually set and maintained during the test, and they are continually monitored by the data acquisition program. Transducer zero readings are recorded at the beginning and end of each test run and are used for applying zero offsets in the data reduction program where transducer output is converted into pressure or temperature values.

Mach number and temperature ratios are computed in a plotting program. Local Mach number is normalized to the jet exit fully-expanded Mach

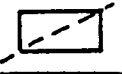
CONFIGURATION	X/D _E	T _j /T _o	M _j	HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
							
0 - 0 (BASELINE)	15	1	0.8	TAB282T	TAB281T	TAB287T	- - - -
	13	1	0.8	TAB302T	TAB293T	TAB145T	- - - -
	11	1	0.8	TAB134T	TAB133T	TAB143T	- - - -
	9	1	0.8	TAB147T	TAB146T	TAB165T	- - - -
	7	1	0.8	TAB130T	TAB129T	TAB144T	- - - -
	5	1	0.8	TAB128T	TAB127T	TAB329T	- - - -
	2	1	0.8	TAB126T	TAB125T	TAB137T	- - - -
	1	1	0.8	- - - -	TAB135T	TAB136T	- - - -
	5	2.3	0.8	TAB337T	TAB338T	TAB343T	- - - -
	7	2.3	0.8	TAB350T	TAB349T	- - - -	- - - -
	9	2.3	0.8	TAB332T	TAB331T	TAB346T	- - - -
	13	2.3	0.8	TAB356T	TAB355T	- - - -	- - - -
	9	1	1.15	TAB185T	TAB203T	- - - -	- - - -
	11	1	0.8	TAB336T	TAB367T	- - - -	- - - -
	13	1	0.8	TAB369T	TAB368T	- - - -	- - - -
BASELINE							
ROUND							

Figure 4.1 Baseline Test Conditions

number as determined by the plenum-to-ambient pressure ratio. Temperatures are presented as ratios of local temperature minus ambient temperature to jet total temperature minus ambient temperature.

4.5 RESULTS

4.5.1 A Note on the Coordinate System

The Cartesian coordinate system (see Figure 4.2) used to describe the measurements locations has the x-axis in the jet flow direction, the y-axis along the major axis direction (3.54 inches, 8.99 centimeters) and the z-axis in the minor axis direction (0.87 inches, 2.21 centimeters). The origin of the coordinate system is the center of the nozzle exit plane. The test conditions are all listed on the right hand side of each figure. The topmost line of this text has the symbols used in a given figure. The dotted line on the insert over the sketch of the rectangular nozzle in the top right of each figure frame indicates whether the measurements direction is horizontal (y), vertical (z), or a diagonal (d).

Note that D_{ej} is the equivalent diameter of a round jet having the same area as the rectangular jet used here. Also note that in the text h_j , w_j , d_j and D_{ej} have been denoted as h , w , d , and D_e .

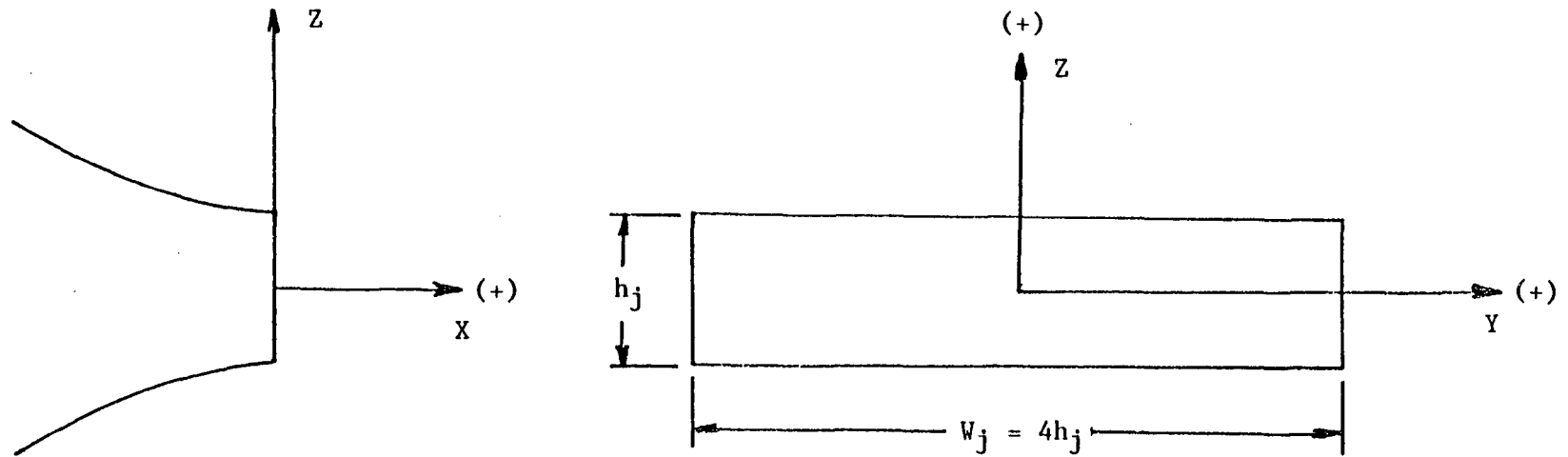


Figure 4.2 Rectangular Jet Coordinate System

4.5.2 Nomenclature for Figures

The basic nomenclature used in the figures is defined in Appendix A. This subsection presents additional comments to further clarify the definition and use of some of the parameter ratios that appear on the right hand side of the figures. Figure 4.3 will be used to define the parameters.

M_j is the fully expanded jet Mach number based on the plenum total pressure and ambient pressure. It includes the effects of variable specific heat ratio.

T_{TJ} and T_A are plenum total temperature and ambient temperature, respectively.

U_j is the velocity corresponding to M_j .

The Reynolds numbers are derived from conditions in the fully expanded jet and are based on equivalent jet diameter (De_j), nozzle height or minor axis length (h), and nozzle width or major axis length (w) as indicated by the subscript.

P_A is the ambient pressure.

X/De_j is the X location of the measurement plane in terms of jet equivalent diameters. X is positive measured downstream from the nozzle exit.

Z/h_j is the vertical offset of a horizontal or diagonal profile. If Z/h_j is zero, the traverse was made through the center of the baseline jet. If it is non-zero, the jet was not centered and the traverse was made at the indicated height in order to pass through the center of the baseline jet on the Z axis. Z is positive above the center of the nozzle exit.

Y/w_j is the horizontal offset of a vertical profile. Y is positive to the right of the nozzle center as viewed from downstream. If Y/w_j is non-zero, the jet was not centered and the traverse was made at the indicated value in order to pass through the center of the baseline jet on the Y axis.

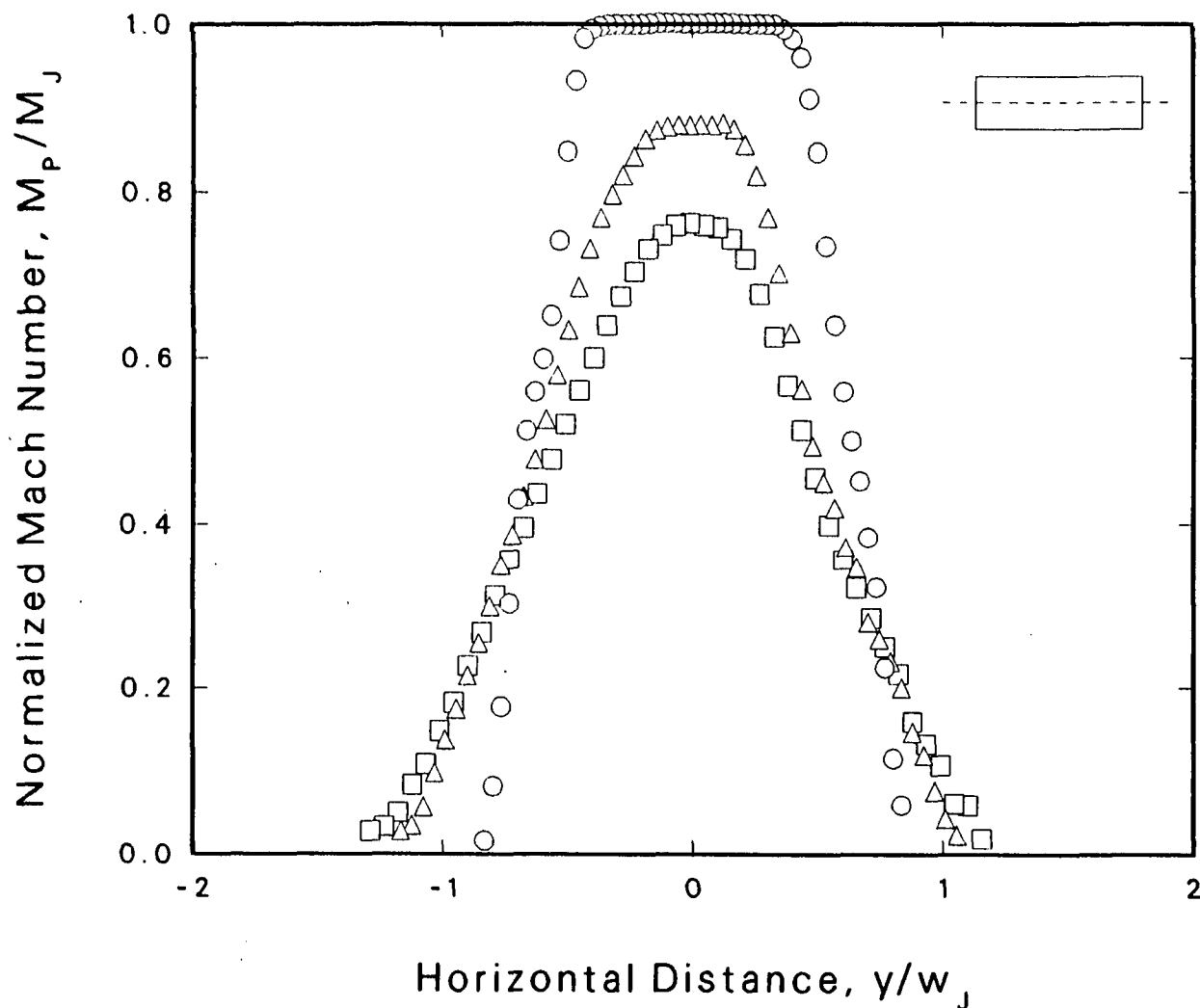
ΔY is the horizontal offset required to center the peak of a horizontal or diagonal profile; ΔZ is the vertical offset required to center a vertical profile. These offsets are used only to center the plots and do not change in any way the tabulated as-run values as given in Volume II. The plots are centered to facilitate the comparison of peak levels and profile shapes.

4.5.3 Mean Velocity and Temperature Profiles

Representative horizontal, vertical, and diagonal profiles at $X/D_e = 2, 5, 7, 9, 11,$ and 13 of Mach number ratio are shown in Figures 4.3 through 4.11. Profiles for the unheated subsonic jets are shown in Figures 4.3 through 4.8 and for the heated subsonic jets in Figures 4.9 through 4.11. Likewise, representative horizontal, vertical, and diagonal profiles of temperature ratio are shown in Figures 4.12 through 4.14. The temperature ratio is defined as follows: $T/T_j = (T_{\text{measured}} - T_{\text{ambient}})/(T_{\text{jet exit}} - T_{\text{ambient}})$, where T is absolute temperature. The entire set of data is presented in Appendix B.

A number of observations can be made from these data:

- (1) The fact that, in Figure 4.3, the Mach number ratio M_p/M_j is 1 at $X/D_e = 2$ and about 0.85 at $X/D_e = 5$, indicates that the potential core exists up to at least $X/D_e = 2$ which corresponds to a distance of about $4.7h$ and $1.13w$. For round subsonic jets, the



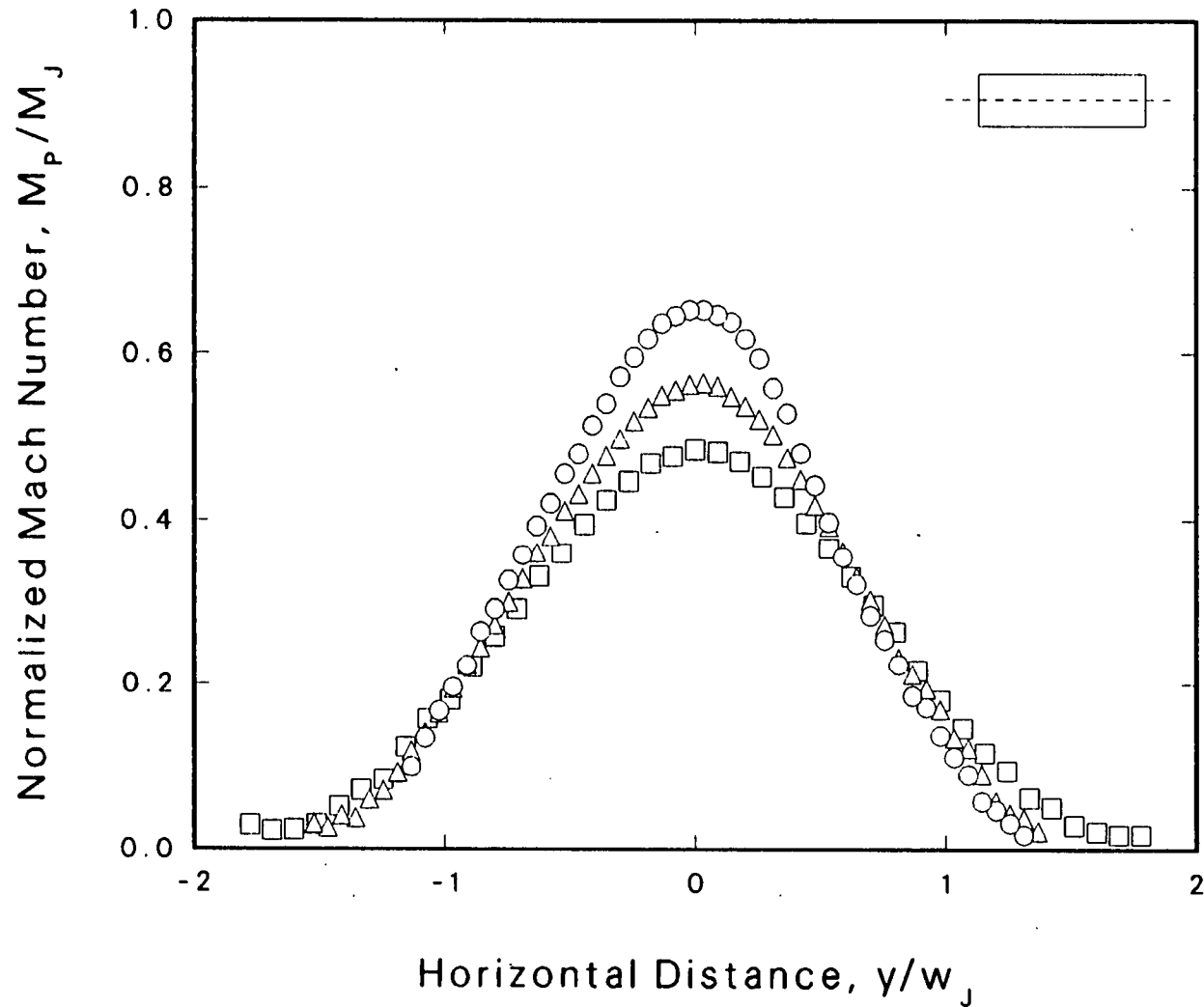
Sym	○	△	□
File	TAB126F	TAB128F	TAB130F
Config	0-0	0-0	0-0
M_j	0.798	0.796	0.797
T_{TJ}/T_A	1.01	1.00	0.97
T_{TJ} , K	285.3	285.3	287.2
U_j , mps	254.5	253.9	255.2
Re_{De}	1.083	1.081	1.072
Re_h	0.480	0.479	0.475
Re_w	1.917	1.913	1.898
p_A , kPa	98.205	98.341	98.171
T_A , K	283.1	284.2	294.6
De_j , mm	50.8	50.8	50.8
X/De_j	2.00	5.00	7.00
Z/h_j	0.02	-0.02	-0.04
ΔY , mm	0.0	5.0	6.0

Figure 4.3 Baseline Horizontal Mach Number Profiles
 $M_j = 0.8$, $T_j/T_o = 1$, $X/D_e = 2$ to 7

potential core length is normally 5 jet exit diameters. This would indicate that if the minor axis nozzle dimension h were used as a characteristic length for the rectangular jet, it would provide a better correlation of potential core length between a rectangular jet and a round jet.

Comparison of Figures 4.3 and 4.4 clearly indicates that the jet decays rather fast beyond $X/D_e = 2$.

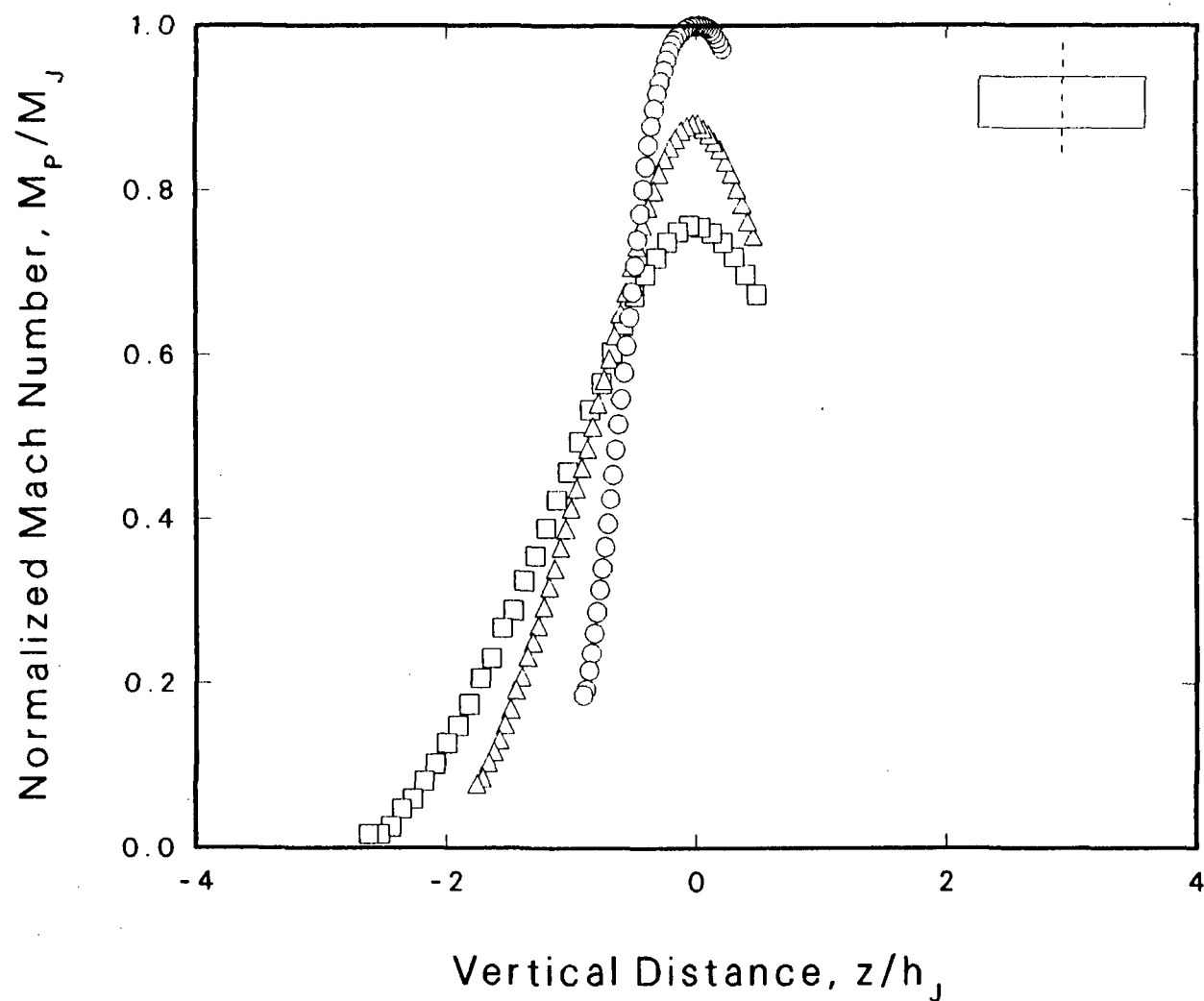
- (2) The conclusions arrived at above also apply to the data presented in Figures 4.5 and 4.6 for the vertical profiles and in Figures 4.7 and 4.8 for the profiles made along the diagonal of the rectangular jet. There is, however, a major difference in the profiles at $X/D_e = 2$. Comparison of the profiles in Figure 4.5 and Figure 4.3 indicates that the potential core is almost like a sharp knife edge along the direction of the major axis. This sharpness clearly reduces for $X/D_e > 7$.
- (3) Temperature profiles at $X/D = 2$ were not available. But the temperature profiles at higher X/D_e appear to be consistent with those for the velocity profiles at the same locations. Figures 4.12 through 4.14 indicate this result.
- (4) Unlike the saddle points observed by some researchers (Reference 17) for low velocity jets, no saddle points were observed in the present velocity profiles.



Sym	○	△	□
File	TAB147F	TAB134F	TAB302F
Config	0-0	0-0	0-0
M_j	0.800	0.802	0.798
T_{TJ}/T_A	0.97	0.98	0.98
T_{TJ} , K	285.5	286.8	282.2
U_j , mps	255.2	256.5	253.2
Re_{De}	1.087	1.085	1.100
Re_h	0.482	0.481	0.487
Re_w	1.925	1.920	1.948
p_A , kPa	98.375	98.375	98.307
T_A , K	294.6	293.7	289.4
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	11.00	13.00
Z/h_j	0.00	-0.09	0.00
ΔY , mm	-8.0	7.0	0.0

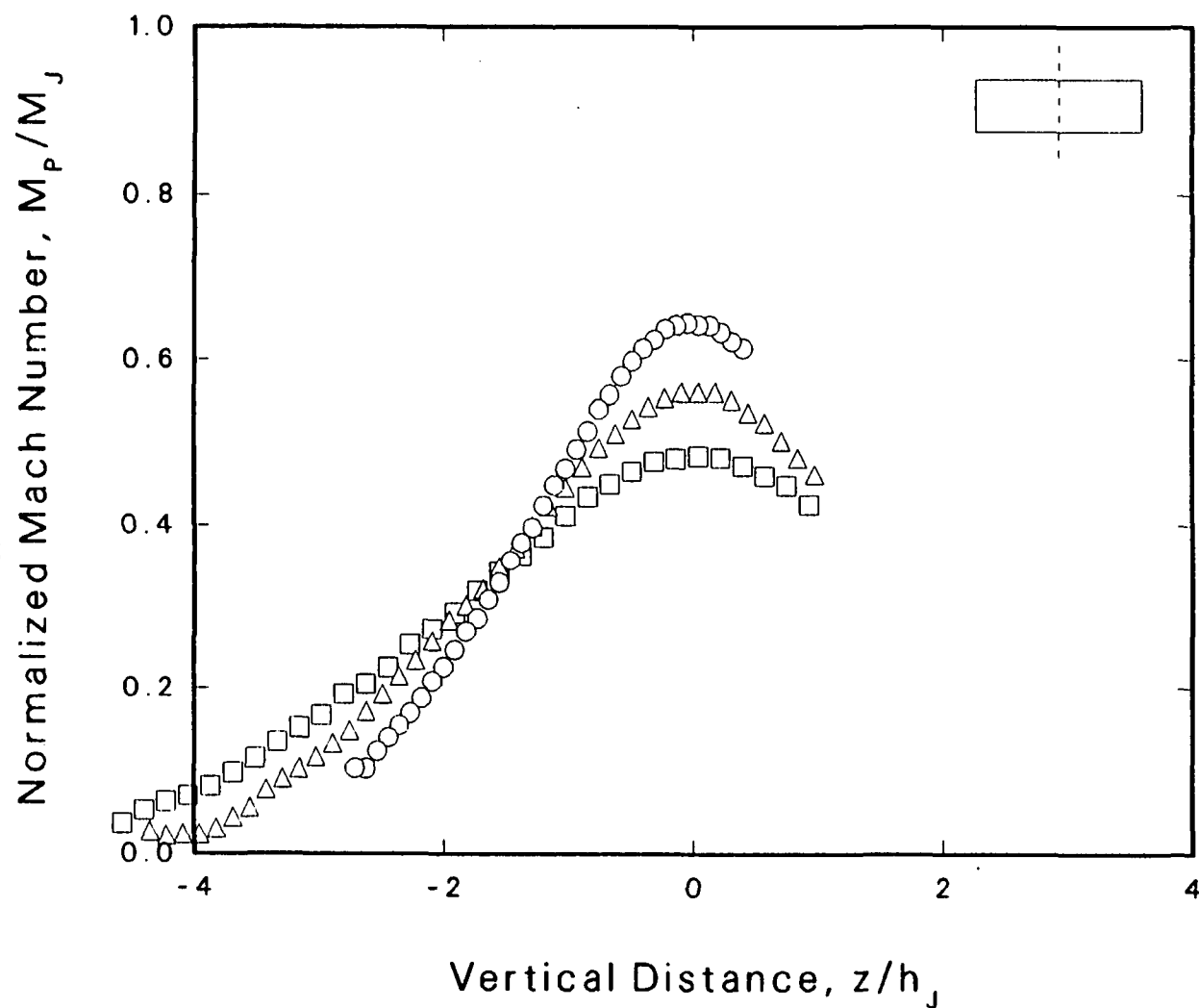
Figure 4.4

Baseline Horizontal Mach Number Profiles
 $M_j = 0.8$, $T_j/T_0 = 1$, $X/D_e = 9$ to 13



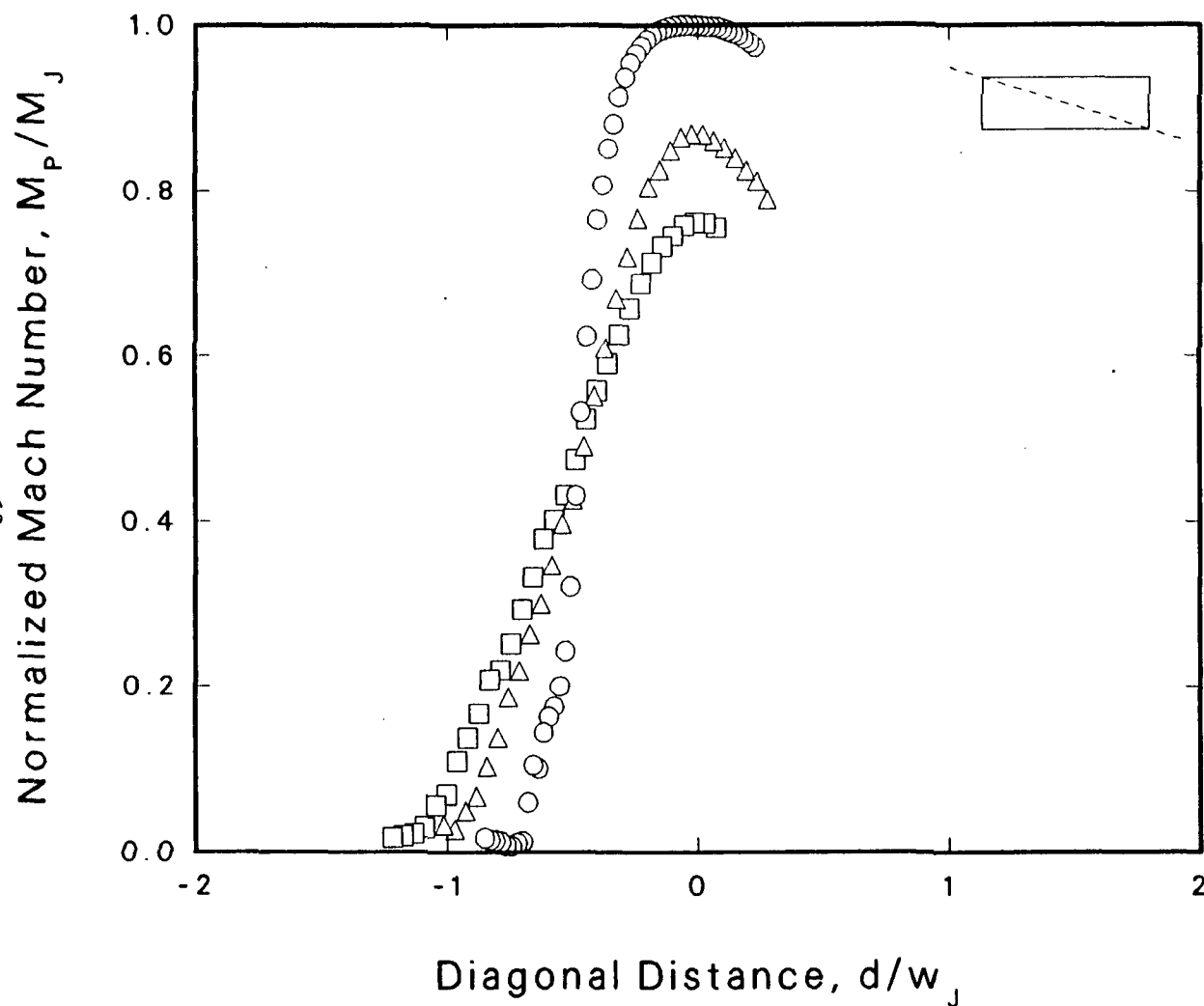
Sym	○	Δ	□
File	TAB125F	TAB127F	TAB129F
Config	0-0	0-0	0-0
M_j	0.798	0.796	0.798
T_{TJ}/T_A	1.01	1.01	0.98
T_{TJ} , K	285.1	285.2	286.6
U_j , mps	254.6	254.0	255.3
Re_{De}	1.084	1.081	1.079
Re_h	0.480	0.479	0.478
Re_w	1.919	1.914	1.910
p_A , kPa	98.171	98.307	98.307
T_A , K	283.5	283.5	291.8
De_j , mm	50.8	50.8	50.8
X/De_j	2.00	5.00	7.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	0.4	-0.5	-1.0

Figure 4.5 Baseline Vertical Mach Number Profiles
 $M_j = 0.8$, $T_j/T_0 = 1$, $X/D_e = 2$ to 7



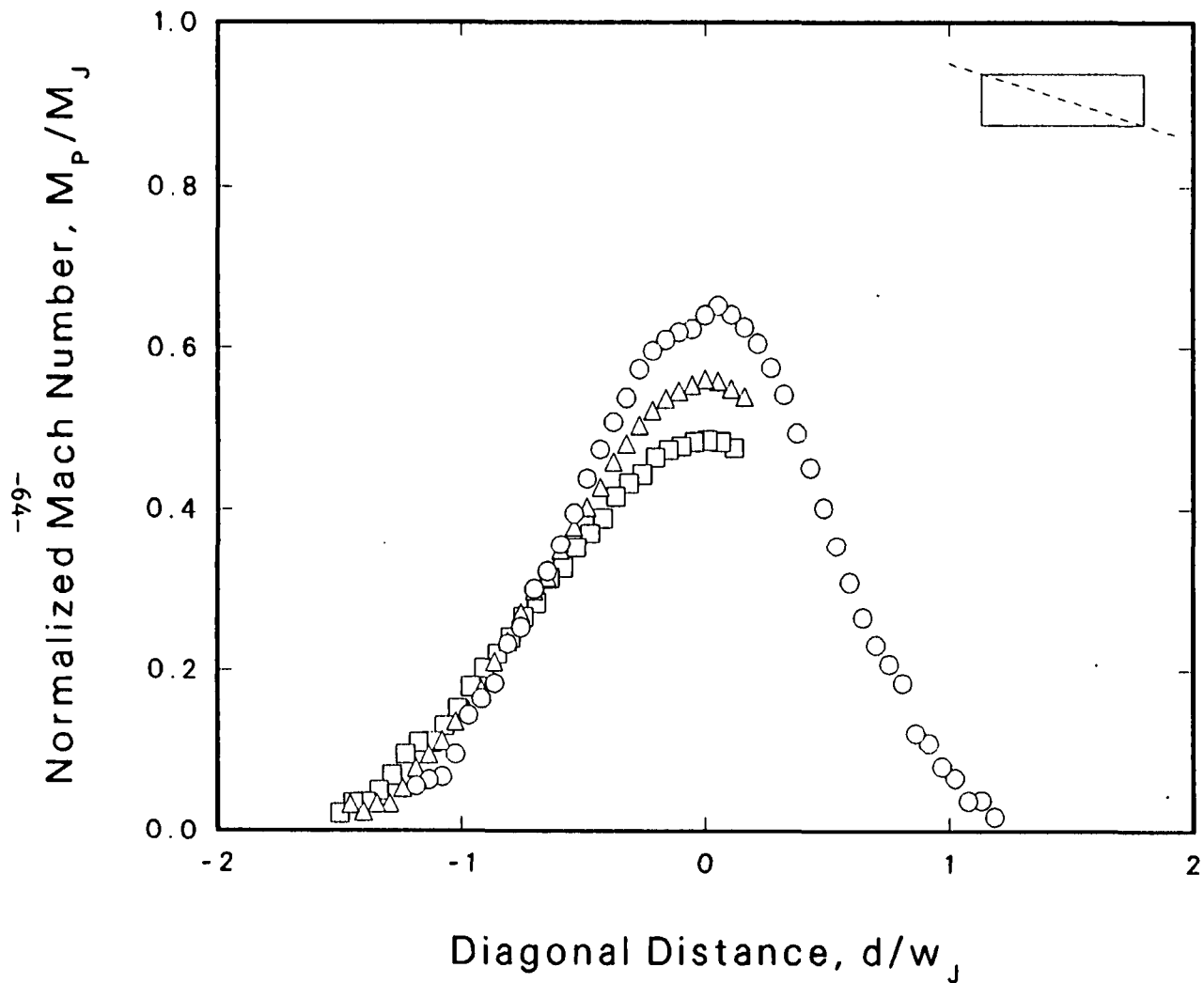
Sym	○	△	□
File	TAB146F	TAB133F	TAB293F
Config	0-0	0-0	0-0
M_j	0.800	0.798	0.798
T_{TJ}/T_A	0.97	0.98	0.98
T_{TJ}, K	285.8	286.9	281.9
U_j, mps	255.4	255.3	253.1
Re_{De}	1.086	1.078	1.095
Re_h	0.481	0.477	0.485
Re_w	1.922	1.908	1.939
p_A, kPa	98.375	98.408	97.731
T_A, K	294.9	293.6	293.2
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	11.00	13.00
Y/w_j	0.00	0.08	0.00
$\Delta Z, mm$	1.0	-2.0	-1.0

Figure 4.6 Baseline Vertical Mach Number Profiles
 $M_j = 0.8$, $T_j/T_0 = 1$, $X/D_e = 9$ to 13



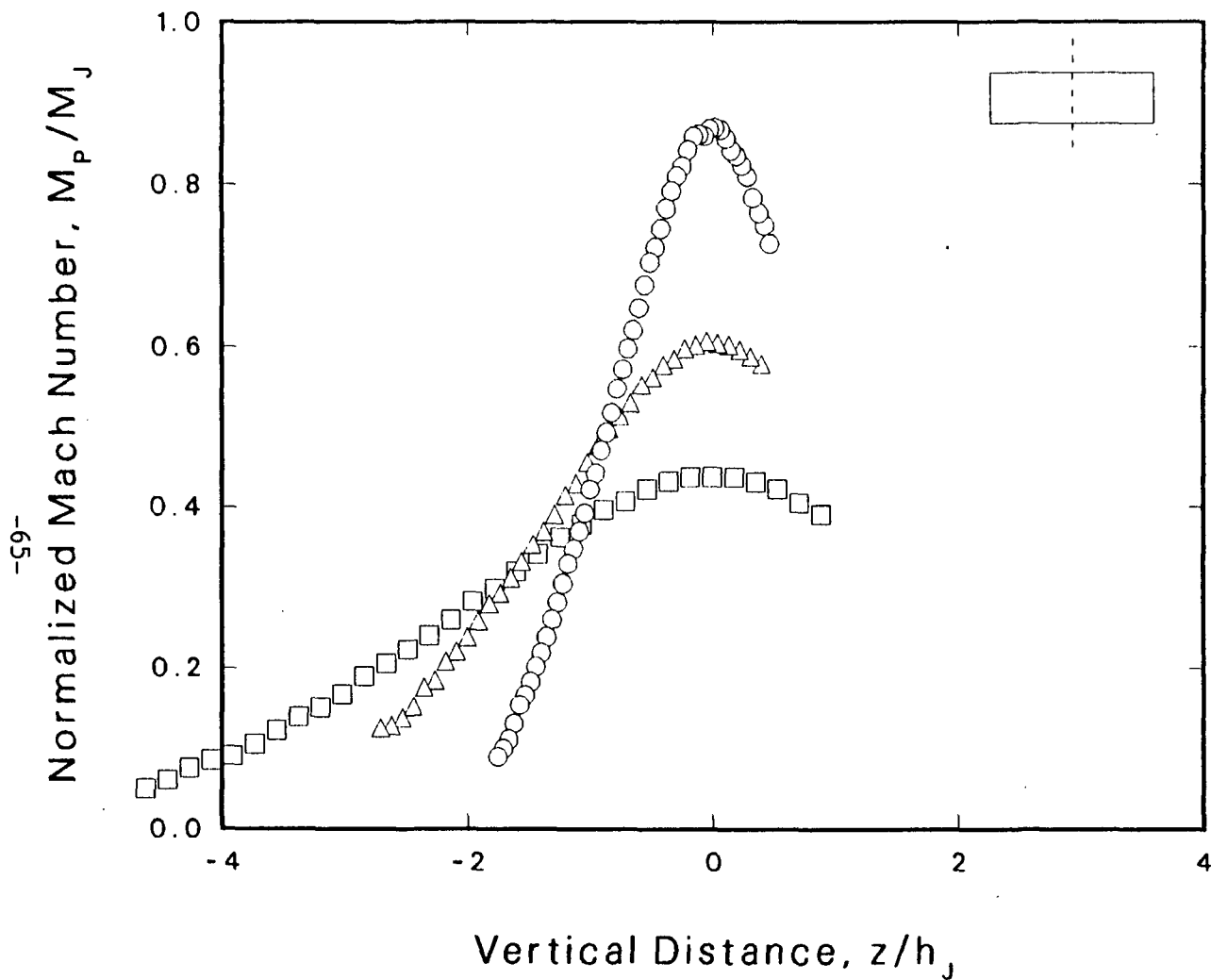
Sym	O	Δ	□
File	TAB137F	TAB329F	TAB144F
Config	0-0	0-0	0-0
M_J	0.798	0.796	0.799
T_{TJ}/T_A	0.99	1.00	0.99
T_{TJ} , K	285.8	279.8	285.4
U_J , mps	254.8	251.7	254.9
Re_{De}	1.077	1.109	1.073
Re_h	0.477	0.491	0.475
Re_w	1.965	2.023	1.957
p_A , kPa	97.833	98.205	97.223
T_A , K	288.5	278.7	288.3
De_J , mm	50.8	50.8	50.8
X/De_J	2.00	5.00	7.00
Z/h_J	0.00	0.00	0.00
ΔY , mm	-1.0	-6.0	3.0

Figure 4.7 Baseline Diagonal Mach Number Profiles
 $M_J = 0.8$, $T_J/T_0 = 1$, $\theta = -14^\circ$, $X/D_e = 2$ to 7



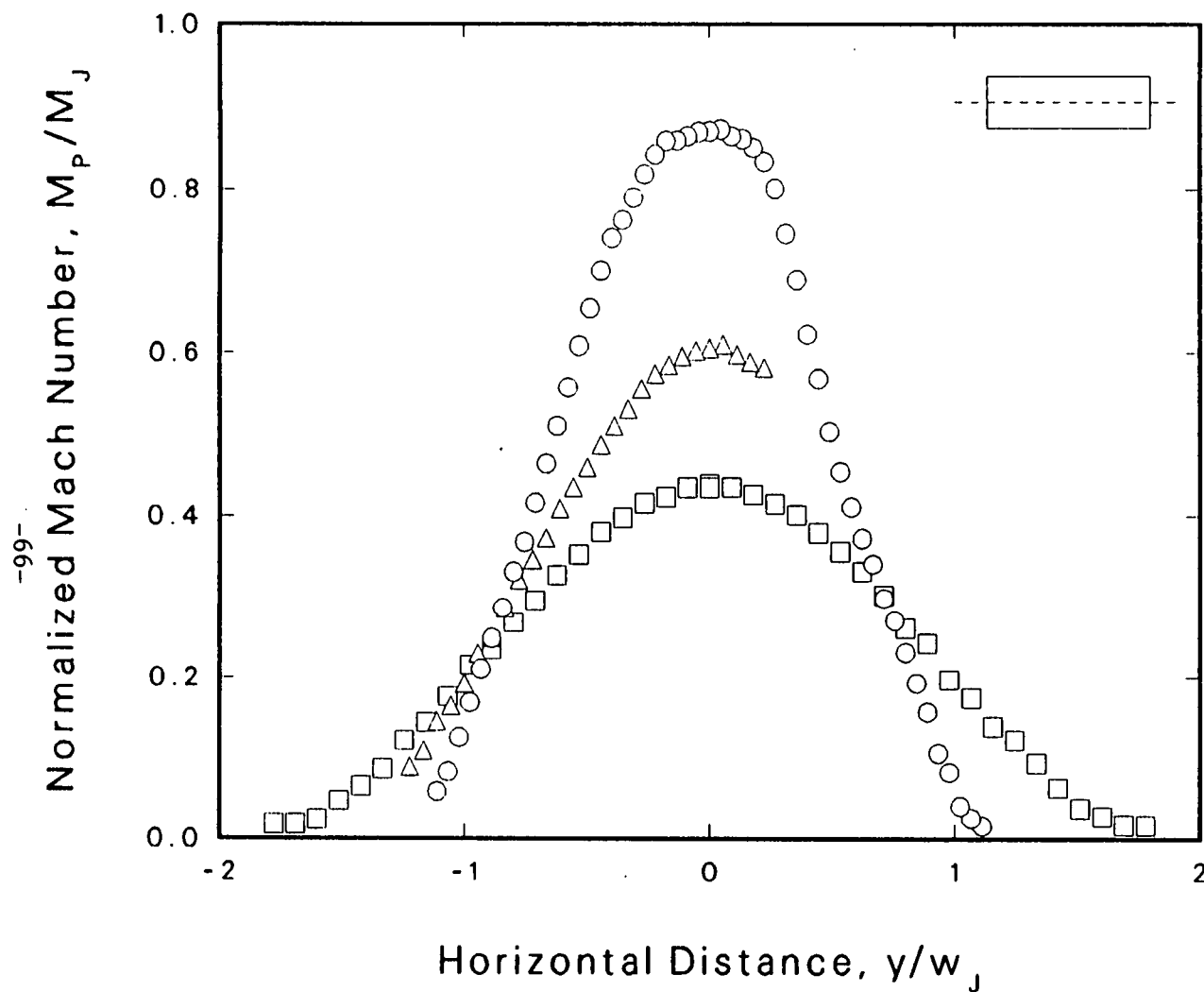
Sym	○	△	□
File	TAB165F	TAB143F	TAB145F
Config	0-0	0-0	0-0
M_j	0.797	0.797	0.802
T_{Tj}/T_A	0.98	1.00	0.99
T_{Tj} , K	285.1	285.1	285.7
U_j , mps	254.3	254.3	256.0
Re_{De}	1.088	1.074	1.071
Re_h	0.482	0.476	0.474
Re_w	1.985	1.960	1.955
p_A , kPa	98.713	97.359	96.648
T_A , K	290.6	285.7	289.5
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	11.00	13.00
Z/h_j	0.00	0.00	0.44
ΔY , mm	0.0	5.0	9.0

Figure 4.8 Baseline Diagonal Mach Number Profiles
 $M_j = 0.8$, $T_j/T_o = 1$, $\theta = -14^\circ$, $X/D_e = 9$ to 13



Sym	○	△	□
File	TAB338T	TAB331T	TAB355T
Config	0-0	0-0	0-0
M_j	0.803	0.802	0.804
T_{Tj}/T_A	2.27	2.29	2.29
T_{Tj}, K	632.2	621.9	651.5
U_j, mps	379.2	375.9	385.5
Re_{De}	0.407	0.411	0.389
Re_h	0.180	0.182	0.172
Re_w	0.720	0.727	0.689
p_A, kPa	98.781	98.002	97.765
T_A, K	277.9	272.0	284.8
De_j, mm	50.8	50.8	50.8
X/De_j	5.00	9.00	13.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	-0.5	1.0	0.0

Figure 4.9 Baseline Vertical Mach Number Profiles
 $M_j = 0.8$, $T_j/T_0 = 2.3$, $X/D_e = 5$ to 13



Sym	○	Δ	□
File	TAB337T	TAB332T	TAB356T
Config	0-0	0-0	0-0
M_j	0.802	0.801	0.804
T_{Tj}/T_A	2.28	2.29	2.29
T_{Tj} , K	632.6	624.8	652.4
U_j , mps	379.0	376.5	385.7
Re_{De}	0.406	0.408	0.388
Re_h	0.180	0.181	0.172
Re_w	0.718	0.723	0.688
p_A , kPa	98.781	97.968	97.765
T_A , K	277.6	272.6	284.4
De_j , mm	50.8	50.8	50.8
X/De_j	5.00	9.00	13.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure 4.10 Baseline Horizontal Mach Number Profiles
 $M_j = 0.8$, $T_j/T_o = 2.3$, $X/De = 5$ to 13

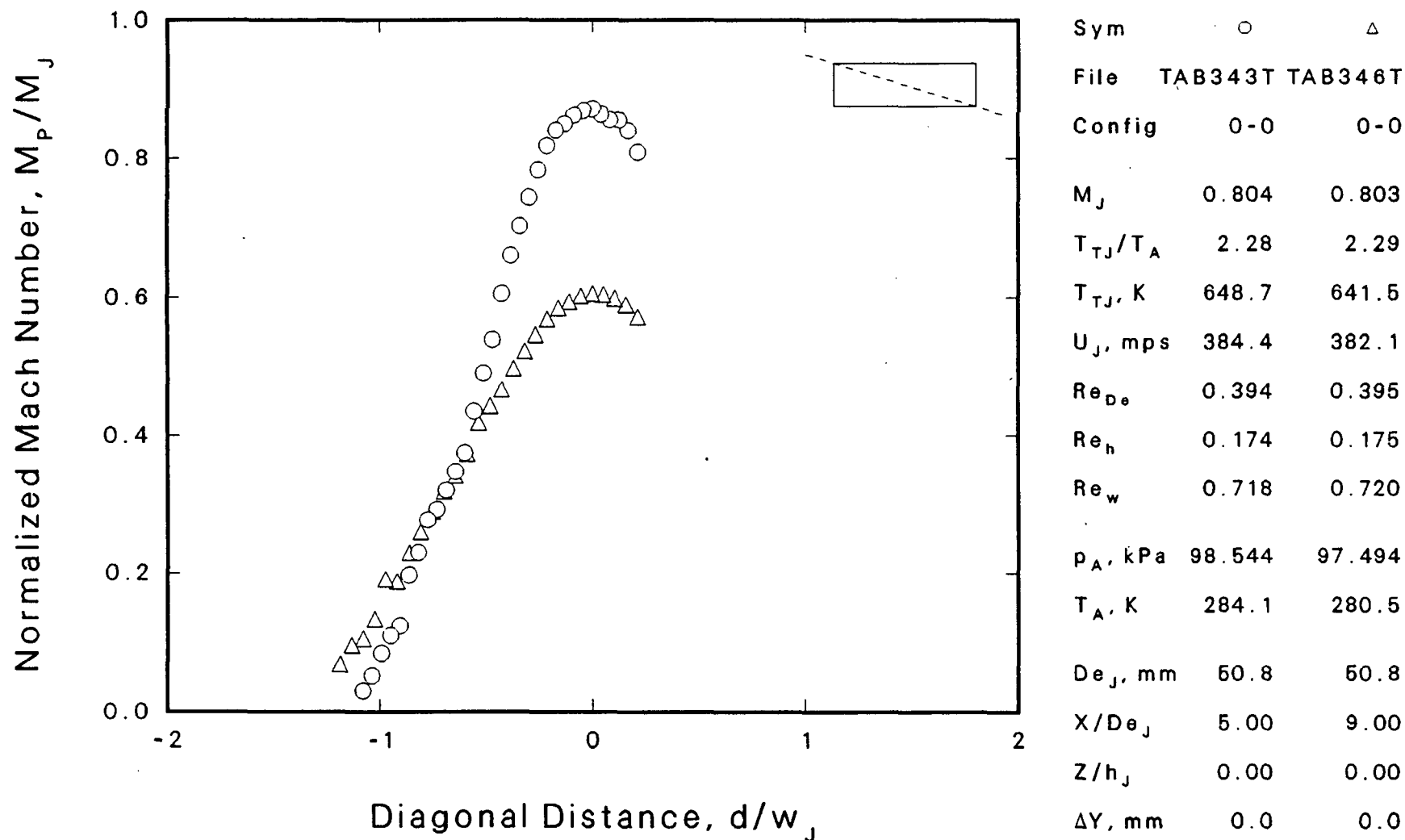
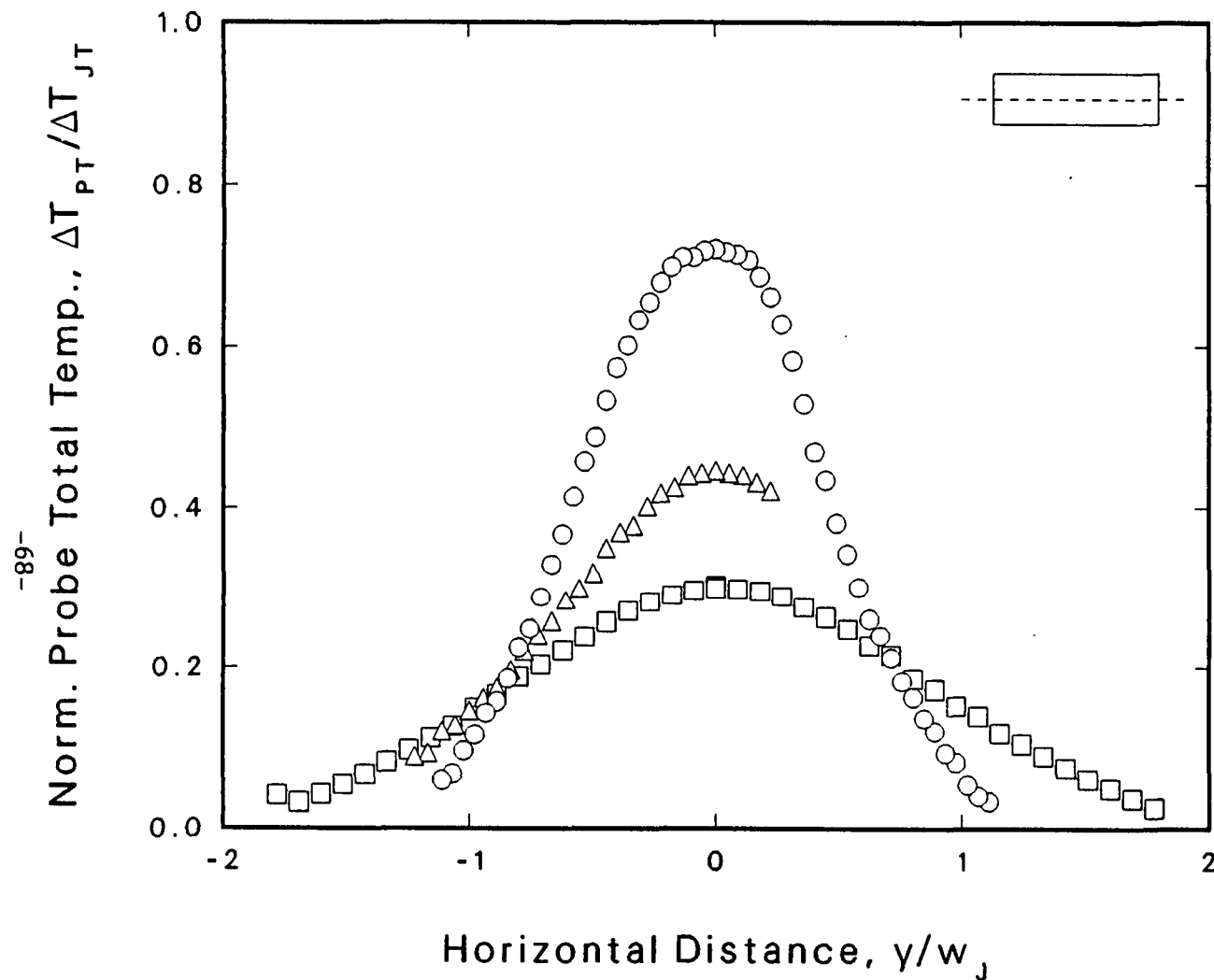
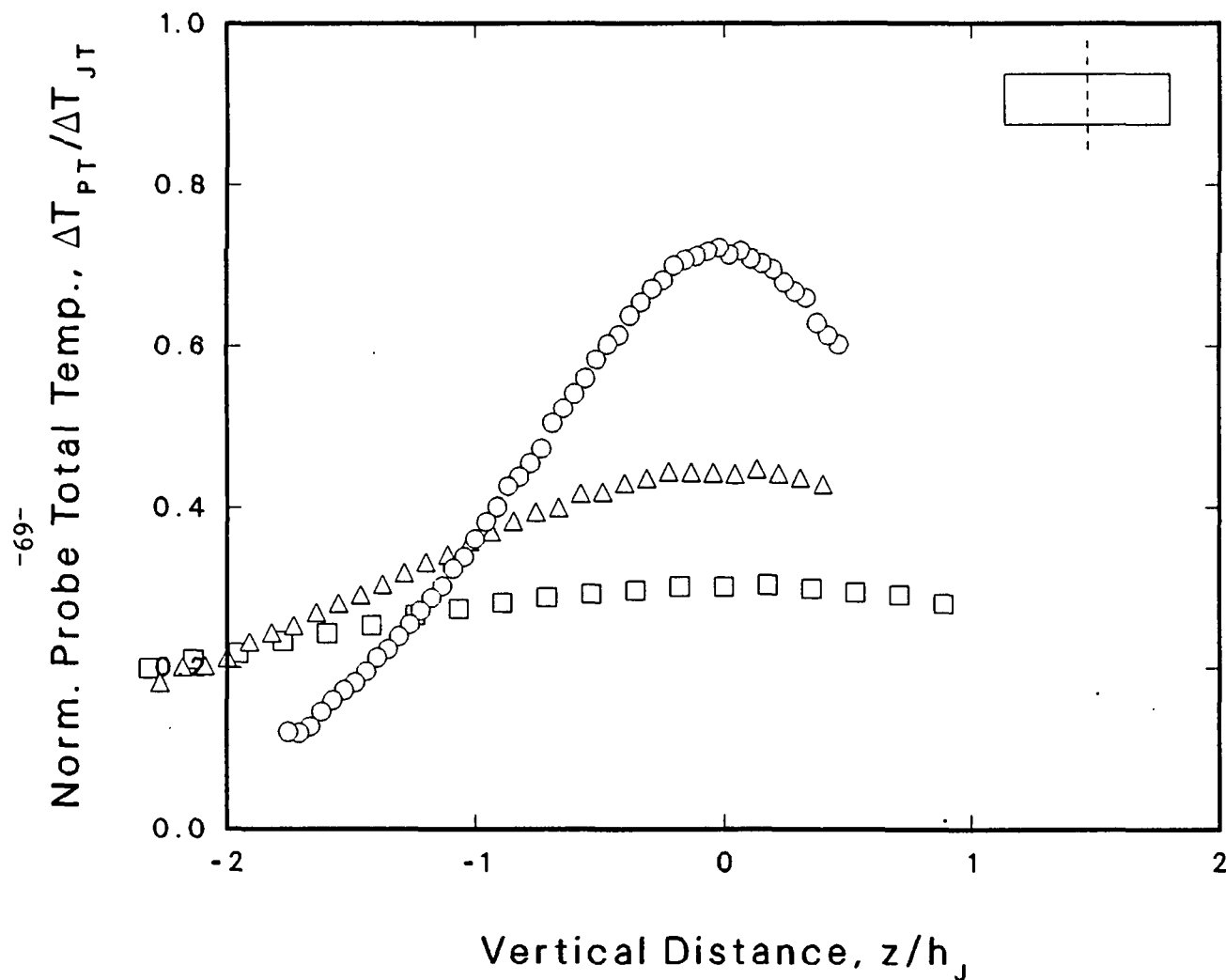


Figure 4.11 Baseline Diagonal Mach Number Profiles
 $M_j = 0.8$, $T_j/T_o = 1$, $\theta = -14^\circ$, $X/D_e = 5$ and 9



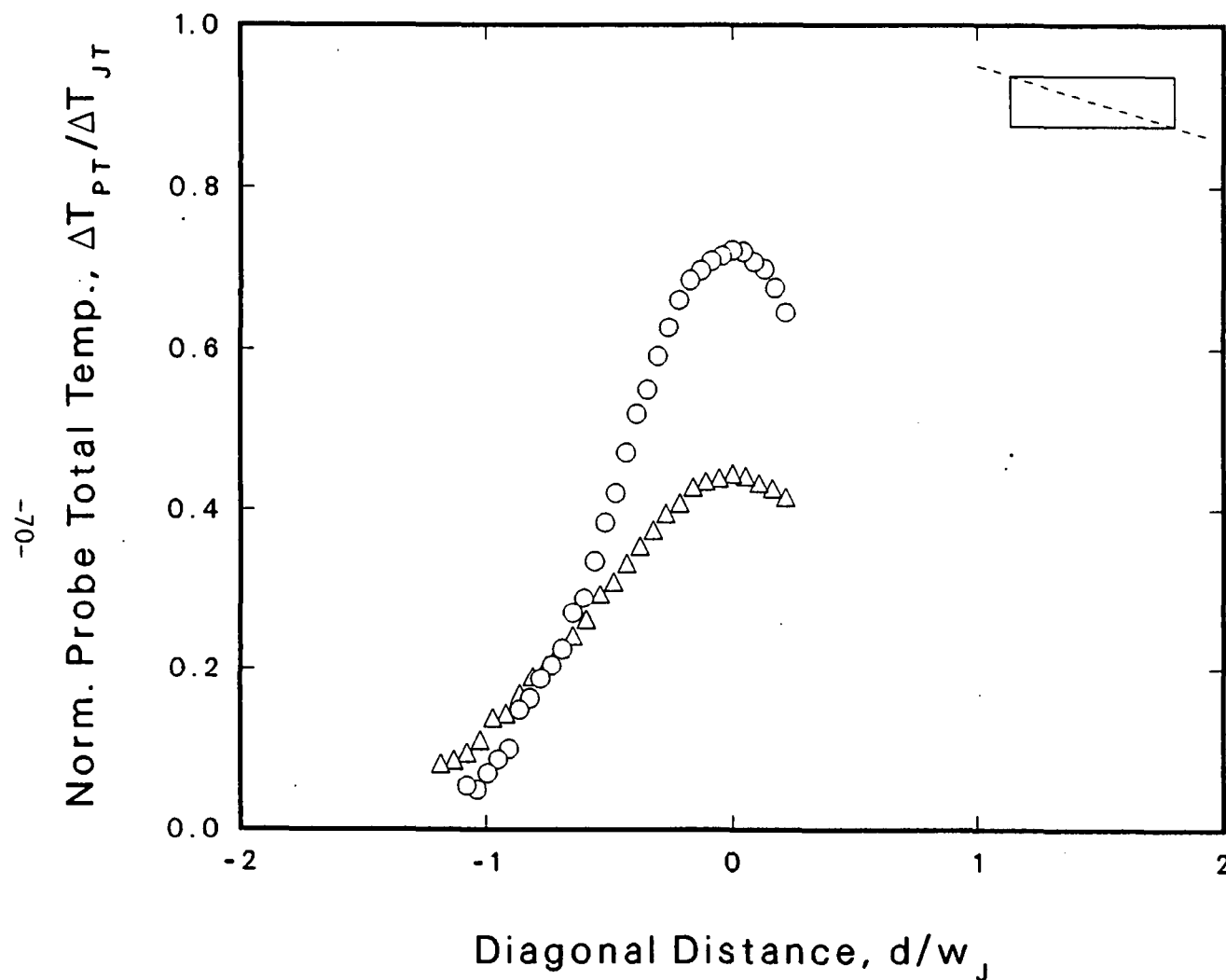
Sym	○	△	□
File	TAB337T	TAB332T	TAB356T
Config	0-0	0-0	0-0
M_J	0.802	0.801	0.804
T_{TJ}/T_A	2.28	2.29	2.29
T_{TJ} , K	632.6	624.8	652.4
U_J , mps	379.0	376.5	385.7
Re_{De}	0.406	0.408	0.388
Re_h	0.180	0.181	0.172
Re_w	0.718	0.723	0.688
p_A , kPa	98.781	97.968	97.765
T_A , K	277.6	272.6	284.4
De_J , mm	50.8	50.8	50.8
X/De_J	5.00	9.00	13.00
Z/h_J	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure 4.12 Baseline Horizontal Static Temperature Profiles
 $M_J = 0.8$, $T_j/T_0 = 1$, $X/De = 5$ to 13



Sym	○	Δ	□
File	TAB338T	TAB331T	TAB355T
Config	0-0	0-0	0-0
M_J	0.803	0.802	0.804
T_{TJ}/T_A	2.27	2.29	2.29
T_{TJ} , K	632.2	621.9	651.5
U_J , mps	379.2	375.9	385.5
Re_{De}	0.407	0.411	0.389
Re_h	0.180	0.182	0.172
Re_w	0.720	0.727	0.689
p_A , kPa	98.781	98.002	97.765
T_A , K	277.9	272.0	284.8
De_J , mm	50.8	50.8	50.8
X/De_J	5.00	9.00	13.00
Y/w_J	0.00	0.00	0.00
ΔZ , mm	-0.5	1.0	0.0

Figure 4.13 Baseline Vertical Static Temperature Profiles
 $M_J = 0.8$, $T_J/T_0 = 1$, $X/De = 5$ to 13



Sym	O	Δ
File	TAB343T	TAB346T
Config	0-0	0-0
M_J	0.804	0.803
T_{TJ}/T_A	2.28	2.29
T_{TJ}, K	648.7	641.5
U_J, mps	384.4	382.1
Re_{De}	0.394	0.395
Re_h	0.174	0.175
Re_w	0.718	0.720
p_A, kPa	98.544	97.494
T_A, K	284.1	280.5
De_J, mm	50.8	50.8
X/De_J	5.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 4.14 Baseline Diagonal Static Temperature Profiles
 $M_j = 0.8$, $T_j/T_0 = 1$, $\theta = -14^\circ$, $X/D_e = 5$ and 9

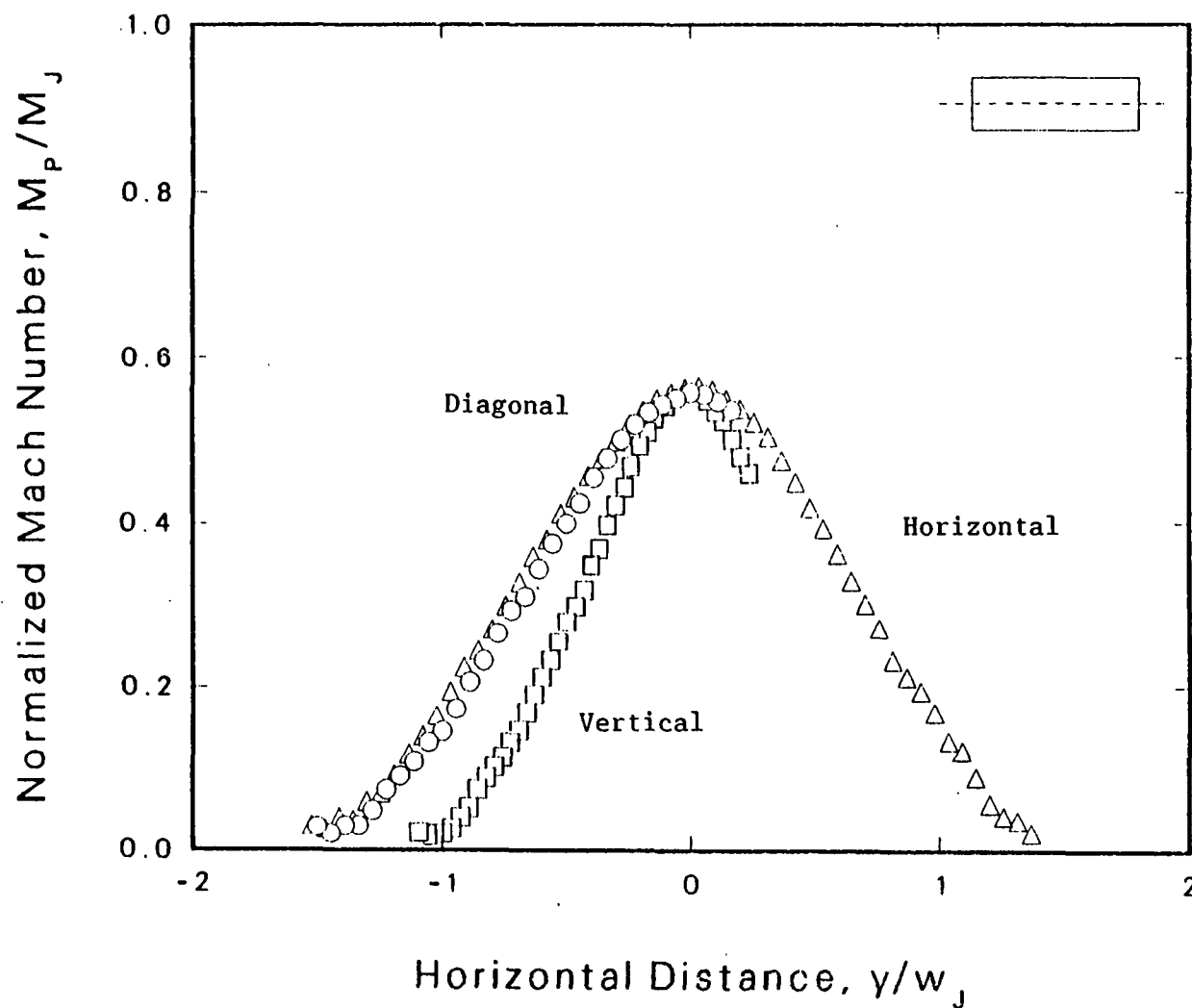
- (5) To determine how long it takes for the jet to become axisymmetric, velocity and temperature profiles along the major, minor, and diagonal axes were superimposed as shown in Figure 4.15 for $X/D_e = 11$ ($X/h = 25.3$) and Figure 4.16 for $X/D_e = 15$ ($X/h = 34$). Clearly, it can be seen that even at $X/D_e = 15$, the velocity profiles are not identical, but they are approaching each other. This indicates that rectangular jets of $AR = 4$ probably become axisymmetrical at distances in excess of 34 times the minor axis jet exit dimension.

4.5.4 Assessment of the Mixing Characteristics of Rectangular Jets

The easiest way to determine if a rectangular jet provides more mixing than a circular jet is to examine the Mach number distribution as a function of downstream distance. This is done by comparing Mach number ratios along the jet centerline of the rectangular jet used in the present study with a 2-inch round jet as shown in Figures 4.17 and 4.18 for the unheated jet and the heated conditions, respectively. It should be recalled that the rectangular nozzle used here has an equivalent diameter of 2 inches (5.08 cm). It can be seen that, for the unheated and the heated case, the rectangular jet provides considerably more mixing than the round jet.

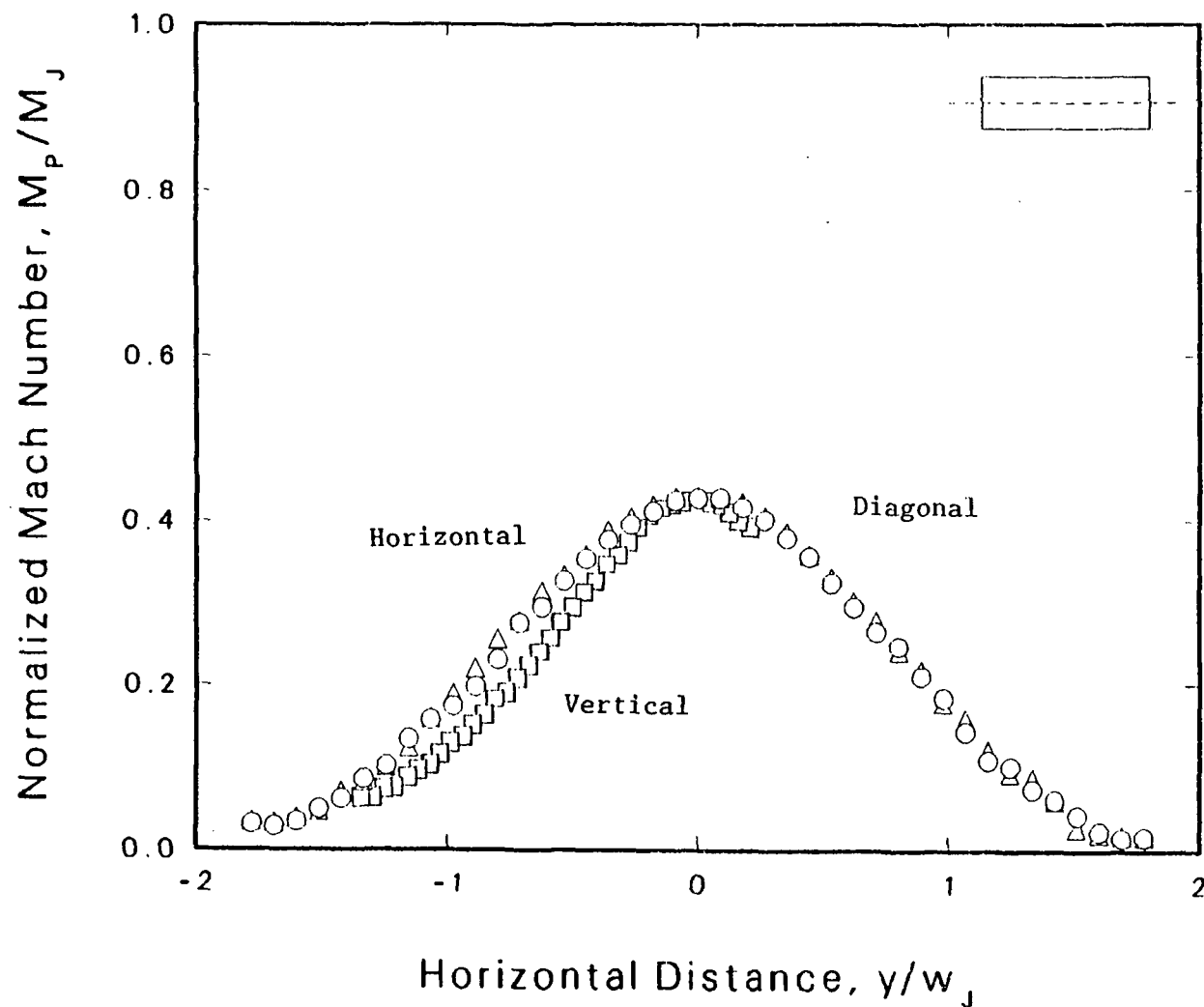
The fact that noncircular jets provide faster mixing than circular jets has been known for a while, but this study appears to be the first one where round and rectangular nozzles of the same area have been used to assess this effect.

A comparison of temperature distribution along the jet centerline for the rectangular and the round jet, presented in Figure 4.19, also shows that the rectangular jets entrain much more ambient air than the round jets.



Sym	○	△	□
File	TAB143T	TAB134T	TAB133T
Config	0-0	0-0	0-0
M_j	0.797	0.802	0.798
T_{TJ}/T_A	1.00	0.98	0.98
T_{TJ}, K	285.1	286.8	286.9
U_j, mps	254.3	256.5	255.3
Re_{D_e}	1.074	1.085	1.078
Re_h	0.476	0.481	0.477
Re_w	1.901	1.920	1.908
p_A, kPa	97.359	98.375	98.408
T_A, K	285.7	293.7	293.6
De_j, mm	50.8	50.8	50.8
X/De_j	11.00	11.00	11.00
Z/h_j	0.00	-0.09	0.08
$\Delta Y, mm$	5.0	7.0	-2.0

Figure 4.15 Comparison of Horizontal, Vertical, and Diagonal Mach Number Profiles at $X/D_e = 11$



Sym	○	△	□
File	TAB287T	TAB282T	TAB281T
Config	0-0	0-0	0-0
M_j	0.797	0.798	0.798
T_{TJ}/T_A	0.98	0.97	0.97
T_{TJ}, K	280.4	280.6	281.3
U_j, mps	252.2	252.6	252.9
Re_{D_e}	1.109	1.110	1.107
Re_h	0.491	0.492	0.490
Re_w	1.964	1.965	1.959
p_A, kPa	98.442	98.442	98.476
T_A, K	286.7	289.8	290.9
De_j, mm	50.8	50.8	50.8
X/De_j	15.00	15.00	15.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	0.0

Figure 4.16 Comparison of Horizontal, Vertical, and Diagonal Mach Number Profiles at $X/D_e = 15$

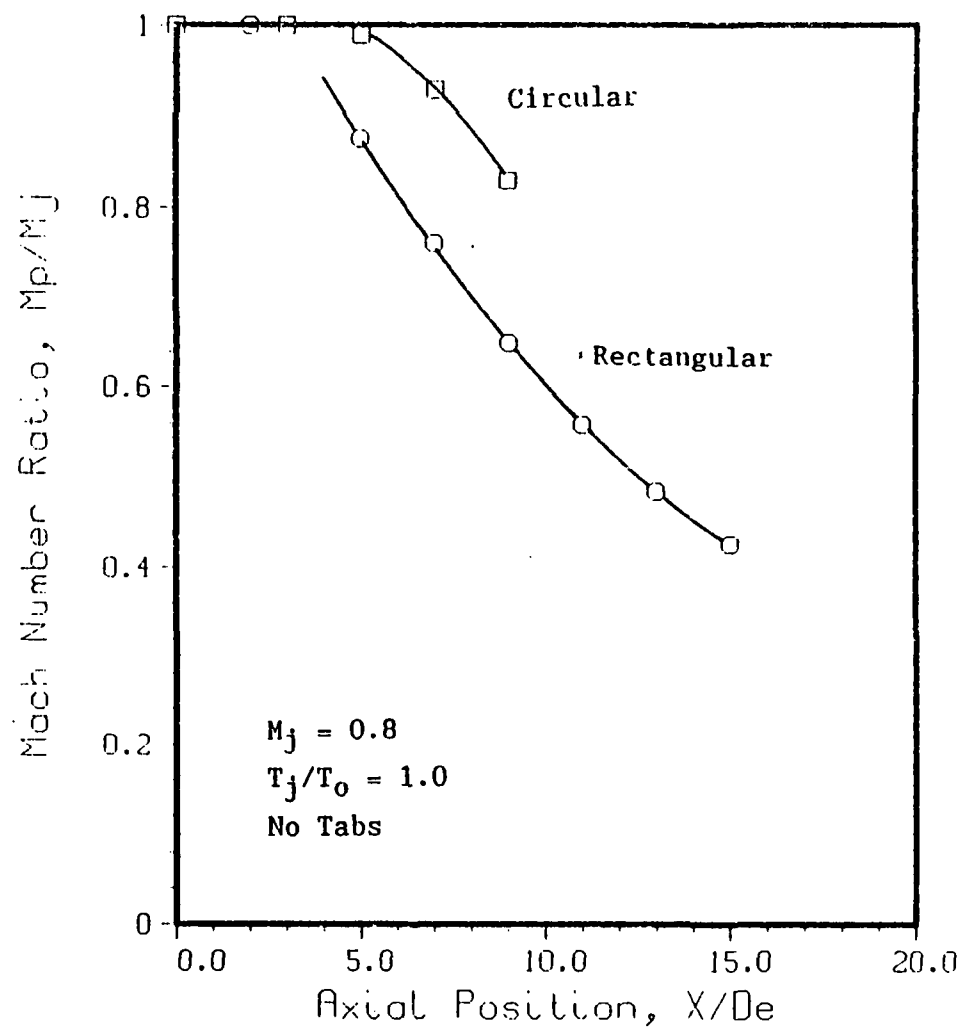
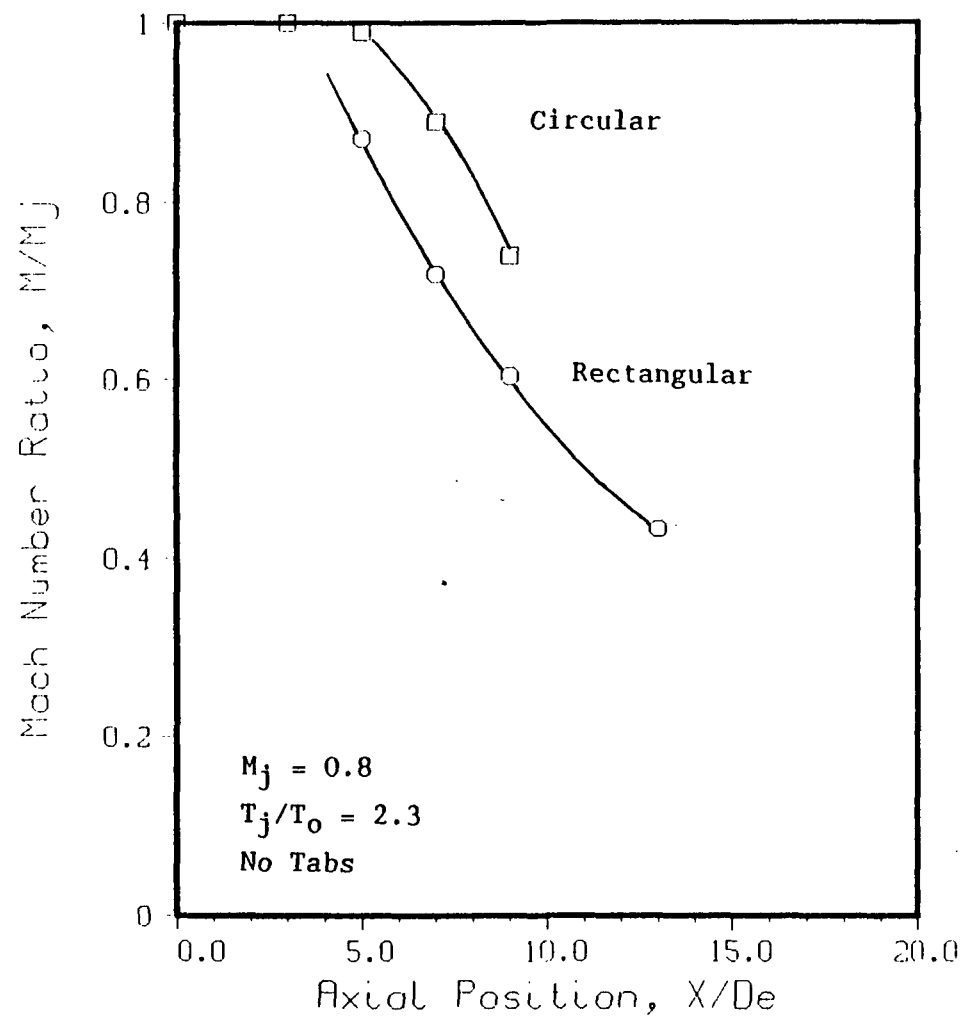


Figure 4.17 Comparison of Mach Number Axial Decay for Unheated Circular and Rectangular Jets



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Figure 4.18 Comparison of Velocity Axial Decay for Heated Circular and Rectangular Jets

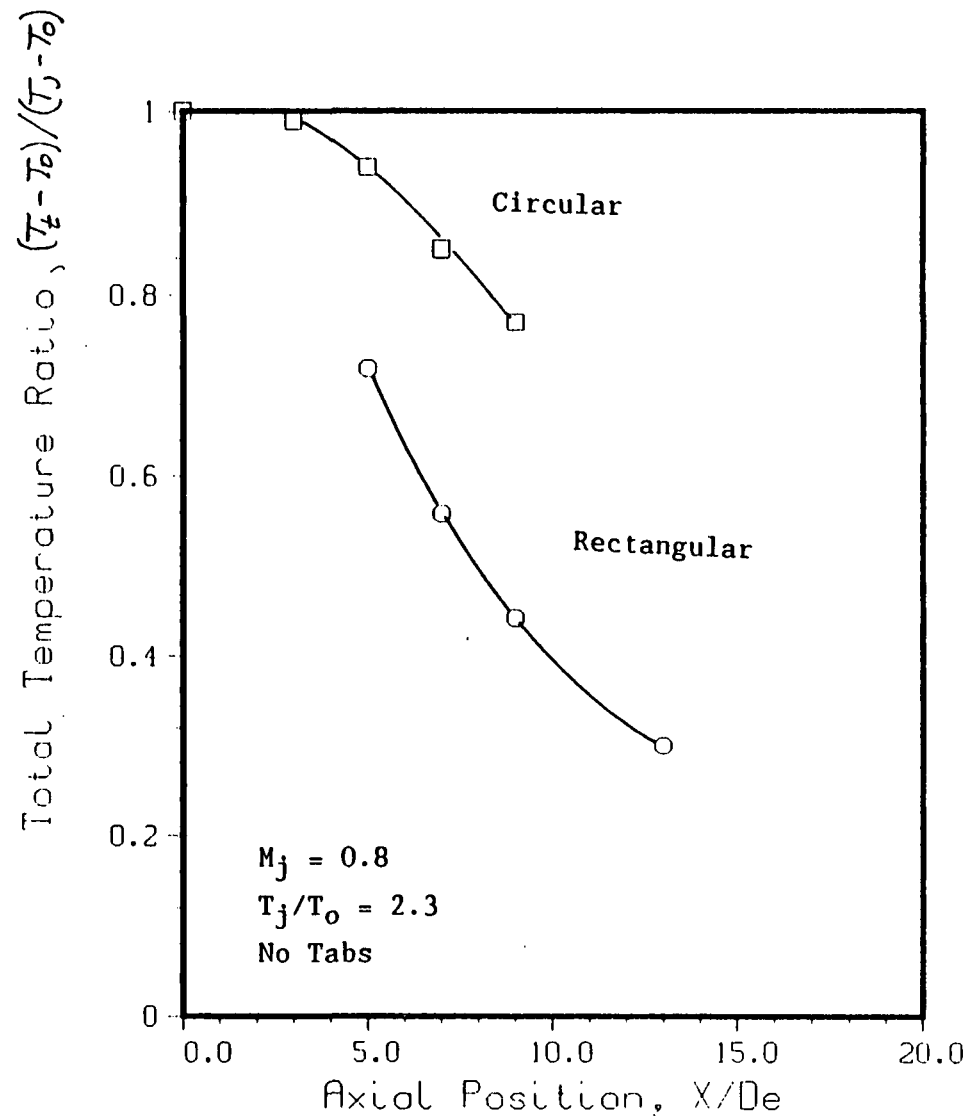


Figure 4.19 Comparison of Temperature Axial Decay for Heated Circular and Rectangular Jets

The temperature of the rectangular jet is much lower than that of the round jet at all axial locations.

It should be noted that data were acquired only for two temperature ratios, namely ambient and $T_j/T_e = 2.3$. The effect of heating was to widen the plume somewhat. This can be seen in Figure 4.20 where the Mach number ratios for the cold and the heated rectangular jets are plotted as a function of axial distances as measured along the jet centerline. The same result was determined for round jets.

4.6 Concluding Comments

Data for a rectangular jet of aspect ratio 4 have been presented for cold and heated conditions. The data presented in this section were acquired as the baseline reference to determine the effect of mechanical tabs on the flow development of rectangular jets.

The major finding of the work reported in this section is that rectangular jets develop much faster than round jets. Whether this growth rate be further enhanced by using mechanical tabs is addressed in the next section.

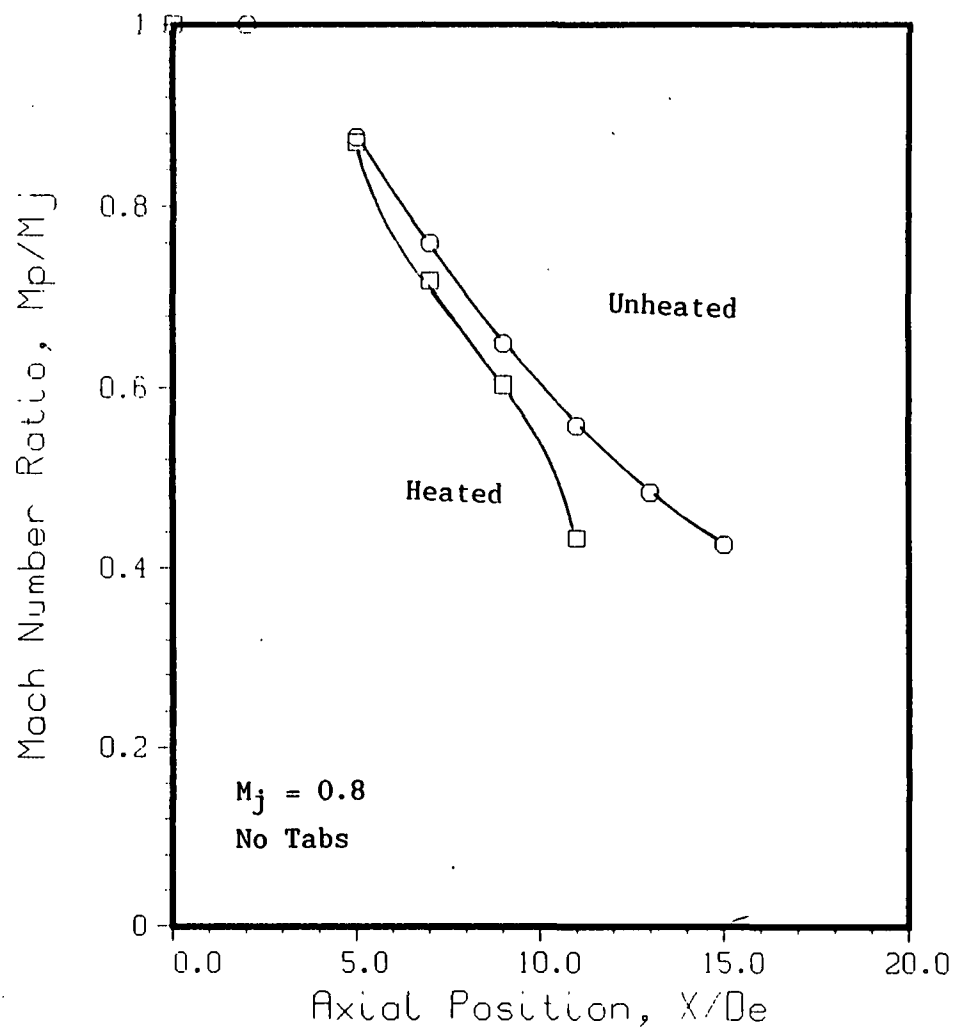


Figure 4.20 Comparison of Mach Number Axial Decay for Unheated and Heated Rectangular Jets

5.0 MIXING MODIFICATION IN RECTANGULAR JETS BY MECHANICAL TABS

5.1 Introduction

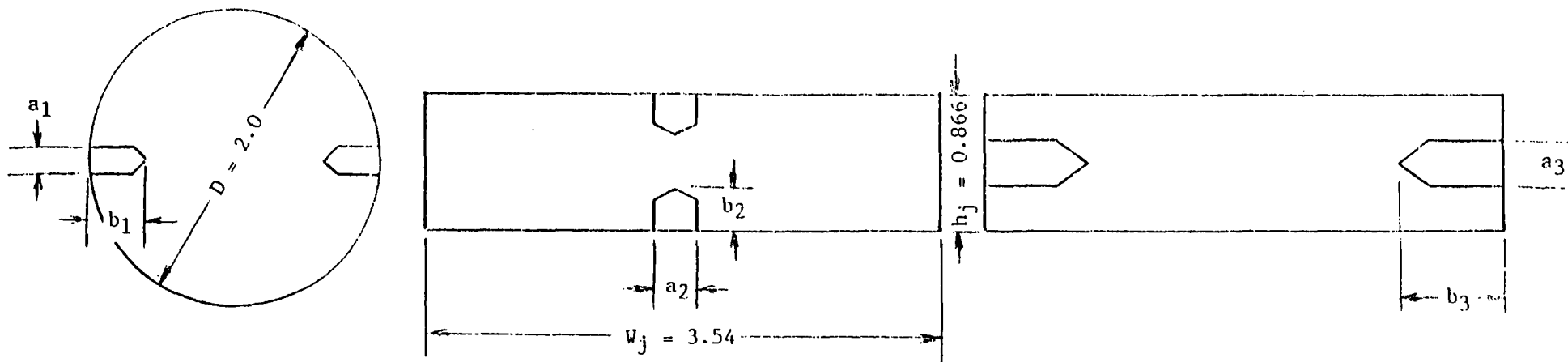
Effects of mechanical tabs on the flow development of a rectangular jet are presented in this section. Three tab sizes were fabricated. The method of scaling the tabs from the round to the rectangular nozzle is shown in Figure 5.1. Tab A was the scaled version of the tab used in the circular nozzle study (Reference 1). Clearly, a configuration with Type A tabs had two different sized tabs along the minor and the major axes. Tab B dimensions were one-and-a-half times those of Tab A, and Tab C was the largest.

Initially, the tests were done with tabs A and B only. It was found that the larger tab, Tab B, provided better mixing than Tab A. The largest tab, Tab C, was then tested for a selected configuration.

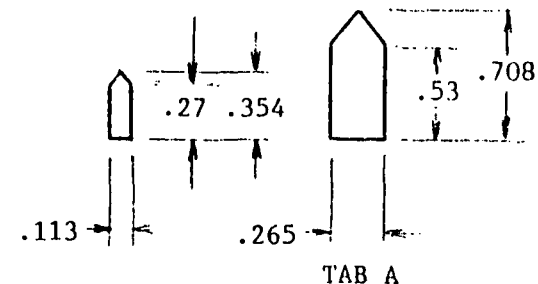
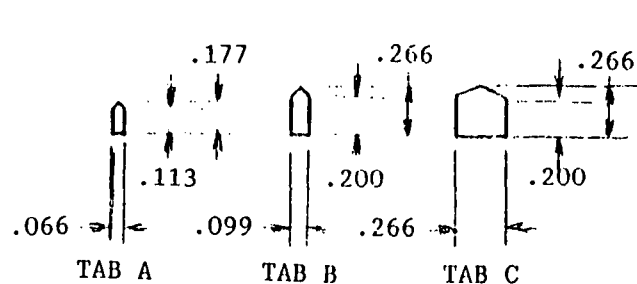
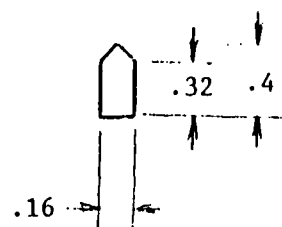
All data with and without the tabs for the various configurations are presented in plotted form in Appendix B of this volume of the report, and the tabulated data are presented separately in Volume II. The data from those configurations that provided noticeably beneficial effect of the mechanical tabs are presented herein.

5.2 Experimental Program

The evaluation of mixing modification in rectangular jets by mechanical tabs was accomplished by comparing the Mach Number and temperature profiles generated by various tab arrangements to those generated by the nozzle alone. The process of doing this is described in the following sub-sections.



-08-



$$\text{TAB A: } \frac{a_2}{h_j} = \frac{a_1}{D}, \quad \frac{b_2}{h_j} = \frac{b_1}{D}$$

$$\text{TAB A: } \frac{a_3}{W_j} = \frac{a_1}{D}, \quad \frac{b_3}{W_j} = \frac{b_1}{W_j}$$

Dimensions in inches.

$$\text{TAB B: } \frac{a_2}{h_j} = 1.5 \frac{a_1}{D}, \quad \frac{b_2}{h_j} = 1.5 \frac{b_1}{D}$$

TAB B:

$$\frac{a_3}{W_j} = \frac{1}{2} \frac{a_1}{D}, \quad \frac{b_3}{W_j} = \frac{1}{2} \frac{b_1}{W_j}$$

$$\text{TAB C: } a_2 = b_2 = 1.5 \frac{b_1}{D}$$

Figure 5.1 Scaling of Tabs from Circular to Rectangular Nozzle

5.2.1 Flow Facility

These experiments were carried out in Lockheed's Jet Flow Facility where most of the aerodynamic data of previously published Lockheed studies on jet mixing was obtained. The facility can supply air at temperatures up to 1000K and pressure ratios exceeding 4. The plenum-to-nozzle area ratio was 25 for the tests reported herein.

5.2.2 Rectangular Nozzle and Tabs

The convergent rectangular nozzle used for this study has an aspect ratio of 4 and is equivalent in area to a 2-inch (5.08 cm) diameter circular nozzle. As shown in Figure 5.2, the lip region of the nozzle provides facilities for locating and securing the tabs in position. More details can be found in Section 2 of this report.

The tabs were machined from bar stock into the shapes shown in Figure 5.2. The initial set of tabs was made in two sizes so that the effects of tab size could be evaluated. Later in the program, an additional size was added for evaluation in one of the configurations.

5.2.3 Test Conditions and Tab Configurations

At the outset of the program, a number of tab configurations were defined for the study. Each configuration consists of a set of "large" tabs or "small" tabs arranged in a unique pattern. The first objective of this part of the program was to eliminate those configurations that showed little promise. This was done by comparing the profiles of each candidate configuration at $X/D=9$ for the cold jet at subsonic and

supersonic conditions. The test conditions and corresponding run numbers are given in Figure 5.3 (a) and (b). Schematics of the test configurations are also shown.

Based on the results of that sorting process, two configurations namely, I-B and III-B, were selected. These provided the final screening of configurations for the cold jet. The conditions and run numbers for this series of tests are given in Figure 5.3 (b).

Lastly, the reduced set of tab configurations was evaluated using a heated subsonic jet as indicated in Figure 5.4. This set of data provides a comparison of the effects on mixing of cold versus heated jets.

5.2.4 Test Methodology

The test runs were computer controlled with respect to probe positioning and data acquisition. Only plenum pressure and temperature were controlled manually. Data file names and comments were added manually when data acquisition was completed. In most of the runs, the first and last test points of each run were measured on the jet axis at $X/D_e = 1$ or 2. This provided readings for the same location taken at the beginning of the test and at the end of the test. A significant difference between the readings would indicate a problem in the data for that test run. Similarly, starting and stopping the tests at the same location provided a quick and easy verification that the traverse was completed successfully.

Separate programs were used to reduce the pressure transducer signals to engineering unit pressures and then to plot Mach number ratio and temperature ratio profiles.

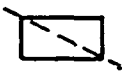
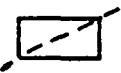
CONFIGURATION	X/D _E	T _j /T _o	M _j	HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
							
0 - 0							
(BASELINE)	9	1	0.8	TAB147T	TAB146T	TAB165T	TAB175T
I - A 	9	1	0.8	TAB157T	TAB158T	TAB168T	TAB176T
I - B 	9	1	0.8	TAB149T	TAB148T	TAB167T	TAB180T
III - A 	9	1	0.8	TAB161T	TAB162T	TAB169T	TAB177T
III - B 	9	1	0.8	TAB155T	TAB156T	TAB170T	TAB181T
II - A 	9	1	0.8	TAB151T	TAB152T	TAB171T	TAB178T
II - B 	9	1	0.8	TAB159T	TAB160T	TAB173T	TAB182T
IV - A 	9	1	0.8	TAB153T	TAB154T	TAB172T	TAB179T
IV - B 	9	1	0.8	TAB163T	TAB164T	TAB174T	TAB183T
VI - A 	9	1	0.8	TAB242T	TAB241T	TAB257T	TAB269T
VI - B 	9	1	0.8	TAB252T	TAB253T	TAB264T	TAB273T
VII - A 	9	1	0.8	TAB239T	TAB240T	TAB256T	TAB268T
VII - B 	9	1	0.8	TAB248T	TAB249T	TAB261T	TAB272T
V - C 	9	1	0.8	TAB275T	TAB276T	TAB260T	TAB274T
I - C 	9	1	0.8	TAB365T	TAB364T	- - - -	- - - -

Figure 5.3 (a) Mixing Modification Test Conditions
and Run Numbers - M_j = 0.8

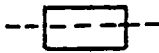
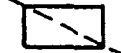
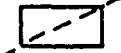
CONFIGURATION	X/D _E	T _j /T _o	M _j	HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
							
0 - 0							
(BASELINE)	9	1	1.15	TAB185T	TAB203T	TAB209T	TAB221T
I - A 	9	1	1.15	TAB187T	TAB204T	TAB210T	TAB223T
I - B 	9	1	1.15	TAB196T	TAB195T	TAB213T	TAB226T
III - A 	9	1	1.15	TAB189T	TAB205T	TAB215T	TAB224T
III - B 	9	1	1.15	TAB198T	TAB197T	TAB214T	TAB227T
II - A 	9	1	1.15	TAB191T	TAB206T	TAB220T	TAB228T
II - B 	9	1	1.15	TAB200T	TAB199T	TAB219T	TAB231T
IV - A 	9	1	1.15	TAB193T	TAB207T	TAB217T	TAB230T
IV - B 	9	1	1.15	TAB202T	TAB201T	TAB218T	TAB232T
VI - A 	9	1	1.15	TAB243T	TAB244T	TAB258T	TAB234T
VI - B 	9	1	1.15	TAB251T	TAB250T	TAB263T	TAB236T
VII - A 	9	1	1.15	TAB238T	TAB237T	TAB255T	TAB233T
VII - B 	9	1	1.15	TAB247T	TAB246T	TAB262T	TAB235T
V - C 	9	1	1.15	TAB278T	TAB277T	TAB259T	TAB266T

Figure 5.3 (b) Mixing Modification Test Conditions
and Run Numbers - M_j = 1.15

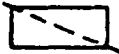
				HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
CONFIGURATION	X/D _E	T _j /T _o	M _j				
I - B 	15	1	0.8	TAB283T	TAB284T	TAB290T	- - - -
	13	1	0.8	TAB295T	TAB294T	TAB291T	- - - -
	11	1	0.8	TAB298T	TAB299T	TAB305T	- - - -
	9	1	0.8	TAB149T	TAB148T	TAB167T	TAB180T
	7	1	0.8	TAB324T	TAB325T	TAB306T	- - - -
	5	1	0.8	TAB321T	TAB320T	TAB308T	- - - -
	2	1	0.8	TAB316T	TAB317T	TAB313T	- - - -
III - B 	15	1	0.8	TAB286T	TAB285T	TAB289T	- - - -
	13	1	0.8	TAB296T	TAB297T	TAB292T	- - - -
	11	1	0.8	TAB301T	TAB300T	TAB304T	- - - -
	9	1	0.8	TAB155T	TAB156T	TAB170T	TAB181T
	7	1	0.8	TAB327T	TAB326T	TAB307T	- - - -
	5	1	0.8	TAB322T	TAB323T	TAB309T	- - - -
	2	1	0.8	TAB319T	TAB318T	TAB311T	- - - -

Figure 5.3 (c) Mixing Modification Test Conditions and Run Numbers - Selected Configurations

C-2

C-2

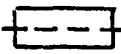
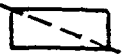
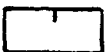
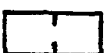
				HORIZONTAL	VERTICAL	DIAGONAL -14°
CONFIGURATION	X/D _E	T _j /T ₀	M _j			
0 - 0 (BASELINE)						
	5	2.3	0.8	TAB337T	TAB338T	TAB343T
	7	2.3	0.8	TAB350T	TAB349T	- - - -
	9	2.3	0.8	TAB332T	TAB331T	TAB346T
	13	2.3	0.8	TAB356T	TAB355T	- - - -
I - B 						
	5	2.3	0.8	TAB340T	TAB339T	TAB344T
	7	2.3	0.8	TAB351T	TAB352T	- - - -
	9	2.3	0.8	TAB333T	TAB334T	TAB347T
	13	2.3	0.8	TAB354T	TAB353T	- - - -
III - B 						
	5	2.3	0.8	TAB341T	TAB342T	TAB345T
	9	2.3	0.8	TAB336T	TAB335T	TAB348T
I - C 						
	9	2.3	0.8	TAB359T	TAB360T	- - - -
	13	2.3	0.8	TAB357T	TAB358T	- - - -

Figure 5.4 Mixing Modification Test Conditions and Run Numbers
- Heated Jet

5.3 Results

5.3.1 Flow Development for Selected Test Configurations

Tab dimensions for test configurations I-B, III-B, II-A, IV-A, V-C, VI-B, VII-B, and I-C are presented in Figure 5.5. Corresponding data for $M_j = 0.8$ for the Mach number profiles at $X/D_e = 9$ are shown for various traverses as described below:

- Figures 5.6 through 5.13: Traverse along the major axis
- Figures 5.14 through 5.21: Traverse along the minor axis
- Figures 5.22 through 5.27: Traverse along the -14° diagonal
- Figures 5.28 through 5.35: Traverse along the $+14^\circ$ diagonal

The following observations can be made from these results:

- (1) With the exception of configuration IV-A, all configurations presented in Figures 5.6 through 5.35 show that the centerline velocity of the jet is indeed reduced by the mechanical tabs.
- (2) Configuration I-B was found to give the best overall result (see Figures 5.6, 5.14, 5.22, and 5.29). Configuration I-C also performed rather well, but the large size of the tab may reduce thrust performance.
- (3) Further assessment needs to be made for configuration I-C because limited data was obtained, as this configuration was studied near the completion phase of the contract.

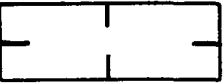
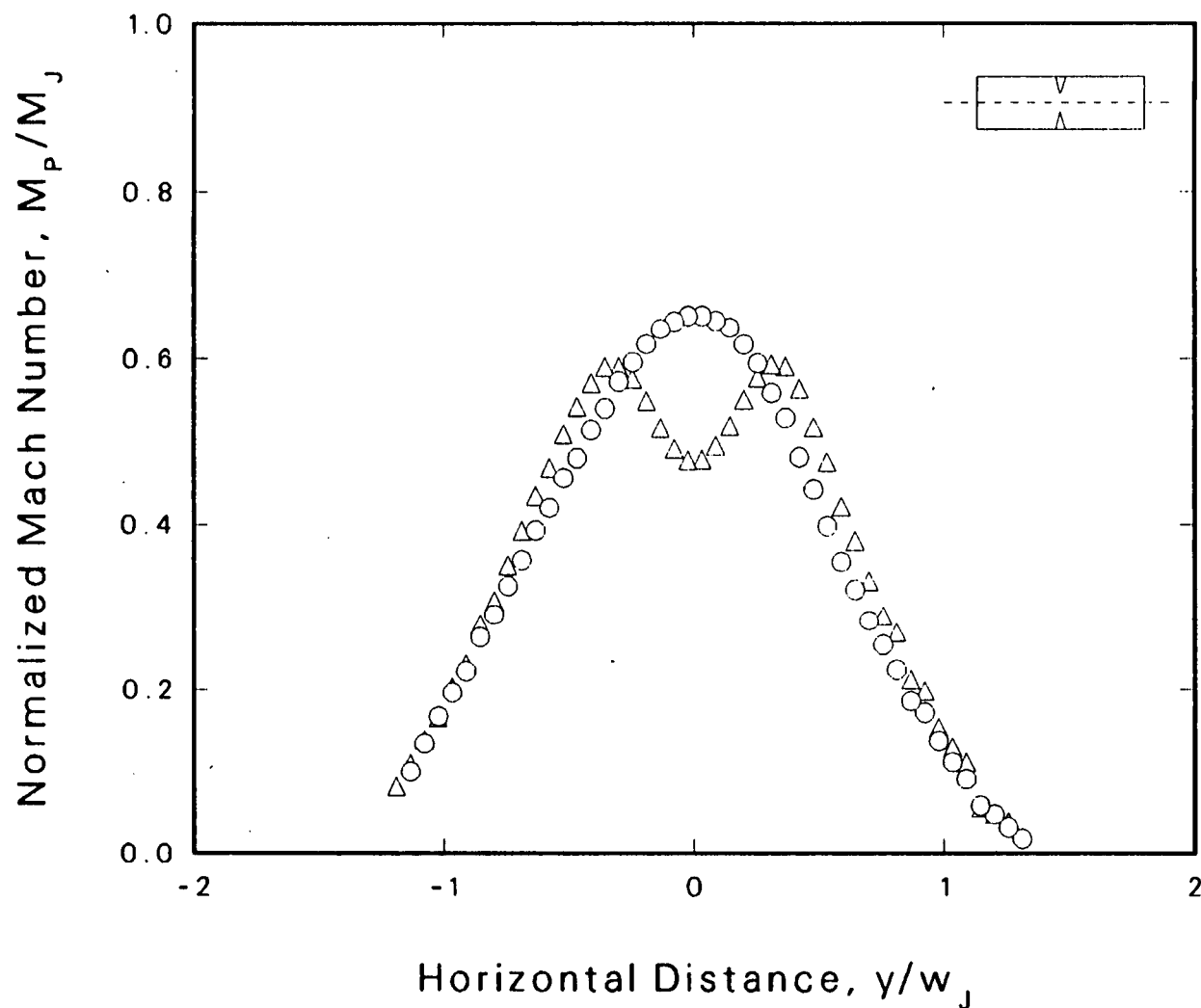
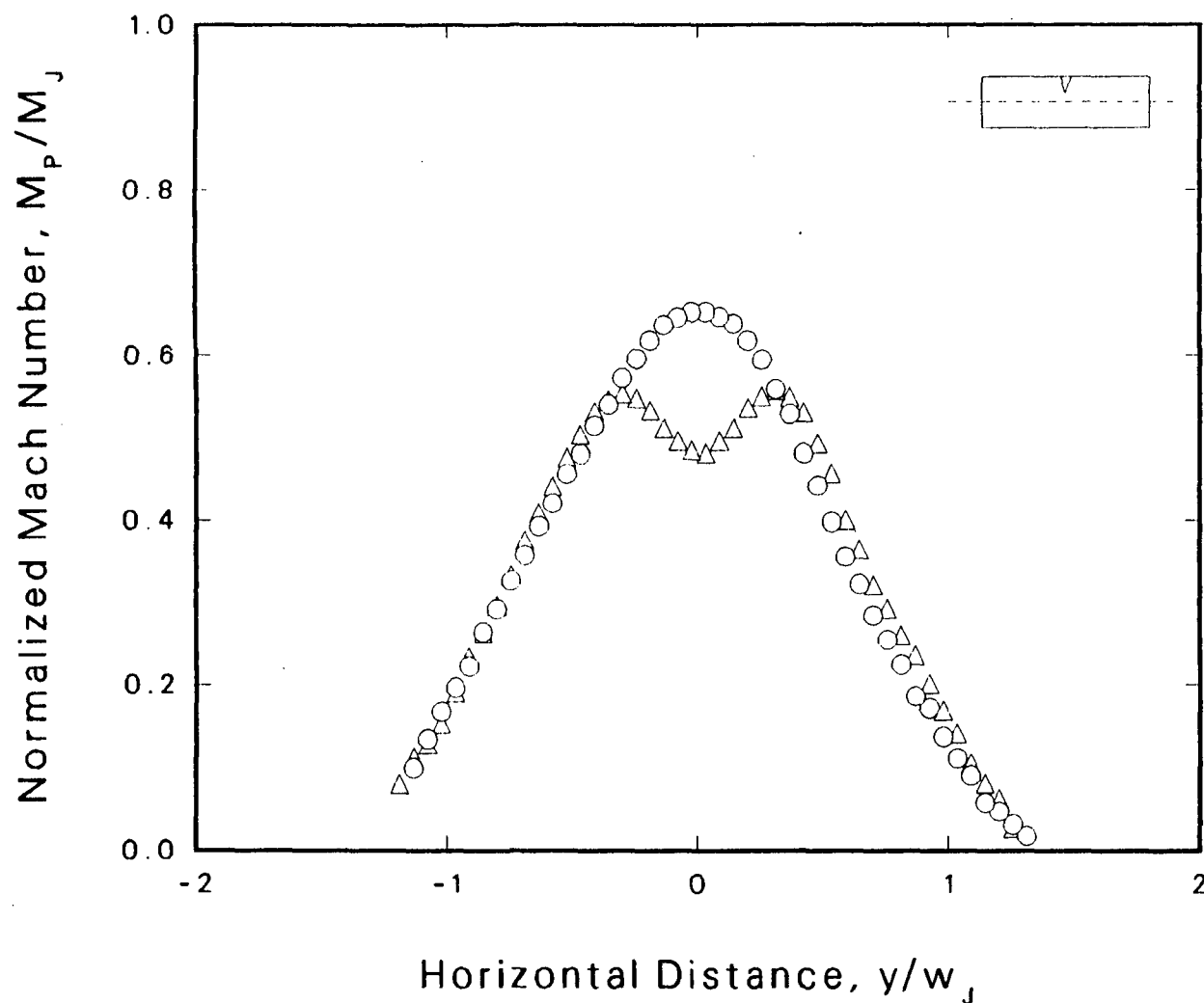
CONFIGURATION		MAJOR AXIS		MINOR AXIS	
		w_p	d_p	w_p	d_p
I-A		- - -	- - -	0.066	0.177
I-B		- - -	- - -	0.099	0.265
I-C		- - -	- - -	0.265	0.265
II-A		0.265	0.708	- - -	- - -
II-B		0.133	0.354	- - -	- - -
III-A		- - -	- - -	0.066	0.177
III-B		- - -	- - -	0.132	0.354
IV-A		0.265	0.708	- - -	- - -
IV-B		0.133	0.354	- - -	- - -
V-C		0.265	0.708	0.099	0.265
VI-A		- - -	- - -	0.066	0.177
VI-B		- - -	- - -	0.099	0.265
VII-A		- - -	- - -	0.066	0.177
VII-B		- - -	- - -	0.099	0.265

Figure 5.5 Tab Sizes by Configuration



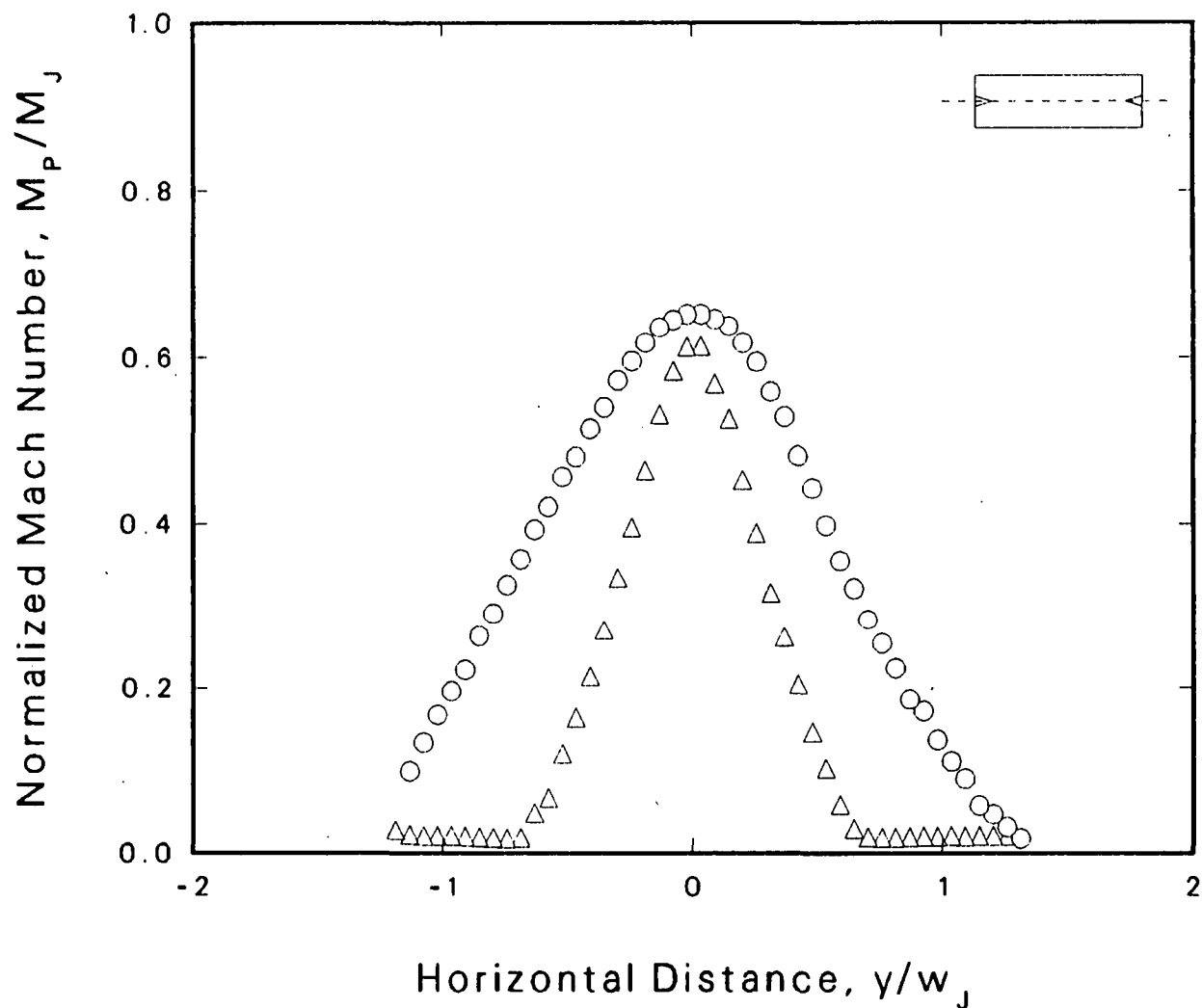
Sym	O	Δ
File	TAB147T	TAB149T
Config	0-0	I-B
M_j	0.800	0.799
T_{Tj}/T_A	0.97	0.97
T_{Tj}, K	285.5	286.0
U_j, mps	255.2	255.3
Re_{De}	1.087	1.083
Re_h	0.482	0.480
Re_w	1.925	1.917
p_A, kPa	98.375	98.239
T_A, K	294.6	294.6
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-8.0	-3.0

Figure 5.6 Horizontal Profile for Configuration I-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



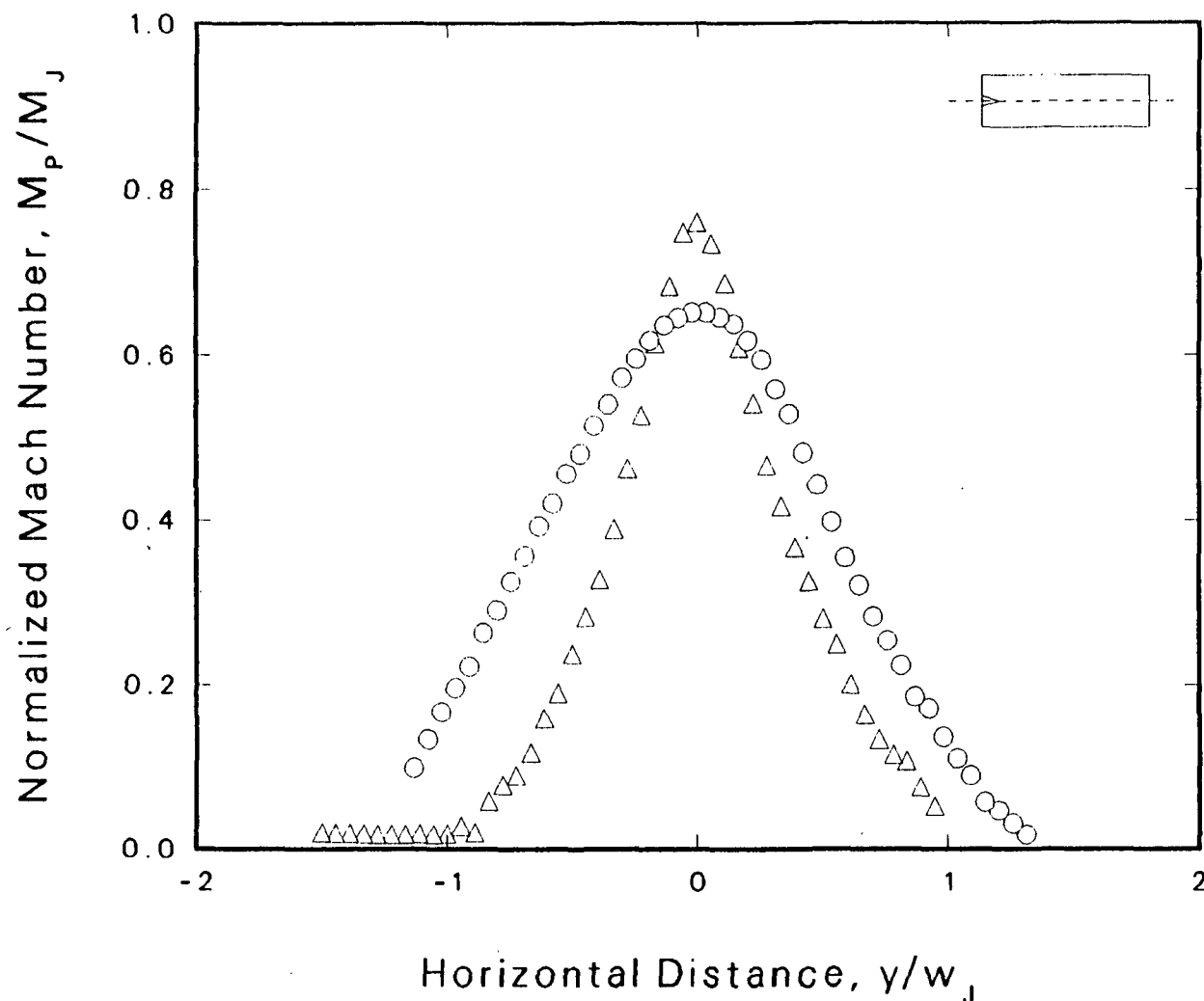
Sym	O	Δ
File	TAB147T	TAB155T
Config	0-0	III-B
M_j	0.800	0.798
T_{Tj}/T_A	0.97	0.97
T_{Tj}, K	285.5	286.3
U_j, mps	255.2	255.1
Re_{De}	1.087	1.074
Re_h	0.482	0.476
Re_w	1.925	1.901
p_A, kPa	98.375	97.833
T_A, K	294.6	296.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-8.0	-3.0

Figure 5.7 Horizontal Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



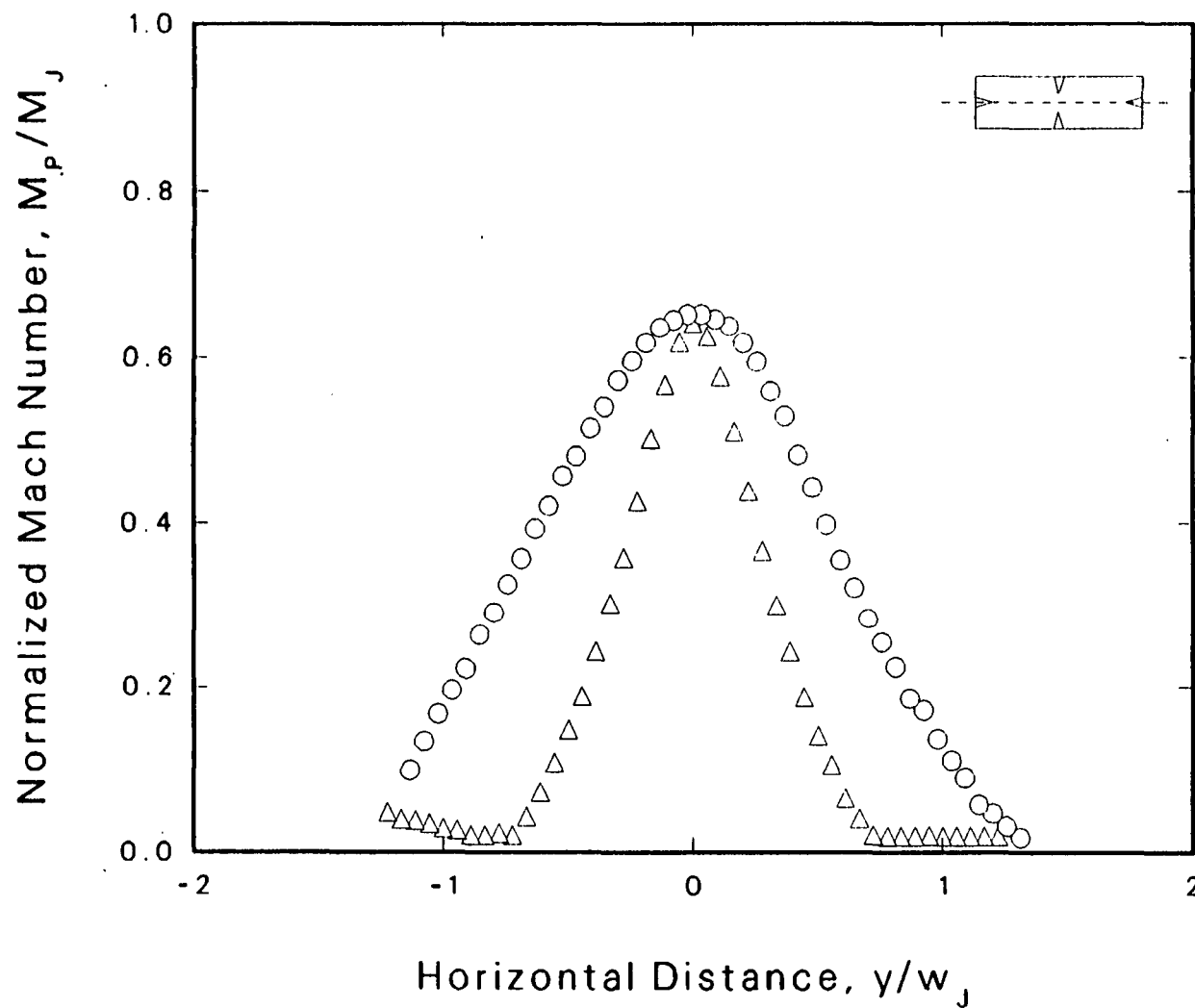
Sym	○	Δ
File	TAB147T	TAB151T
Config	0-0	II-A
M_j	0.800	0.798
T_{TJ}/T_A	0.97	0.97
T_{TJ}, K	285.5	285.8
U_j, mps	255.2	254.8
Re_{D_e}	1.087	1.080
Re_h	0.482	0.479
Re_w	1.925	1.912
p_A, kPa	98.375	98.205
T_A, K	294.6	293.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-8.0	-3.0

Figure 5.8 Horizontal Profile for Configuration II-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



Sym	○	△
File	TAB147T	TAB153T
Config	0-0	IV-A
M_j	0.800	0.797
T_{TJ}/T_A	0.97	0.97
T_{TJ}, K	285.5	286.4
U_j, mps	255.2	254.9
Re_{De}	1.087	1.075
Re_h	0.482	0.476
Re_w	1.925	1.902
p_A, kPa	98.375	98.070
T_A, K	294.6	294.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-8.0	25.0

Figure 5.9 Horizontal Profile for Configuration IV-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



Sym	O	Δ
File	TAB147T	TAB275T
Config	0-0	V-C
M_j	0.800	0.798
T_{Tj}/T_A	0.97	0.98
T_{Tj} , K	285.5	280.0
U_j , mps	255.2	252.4
Re_{De}	1.087	1.113
Re_h	0.482	0.493
Re_w	1.925	1.970
p_A , kPa	98.375	98.408
T_A , K	294.6	285.6
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	-8.0	0.0

Figure 5.10 Horizontal Profile for Configuration V-C
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$

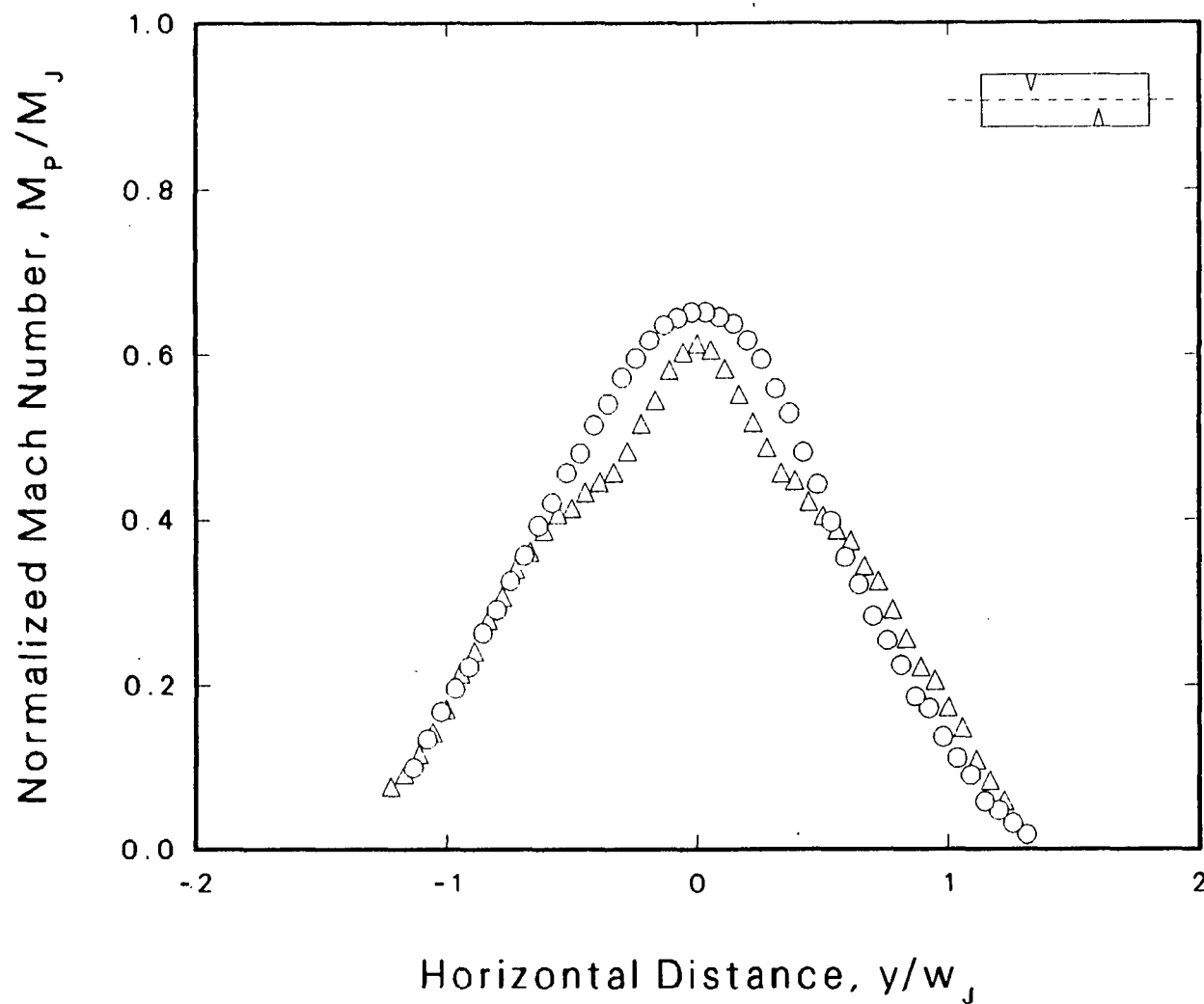
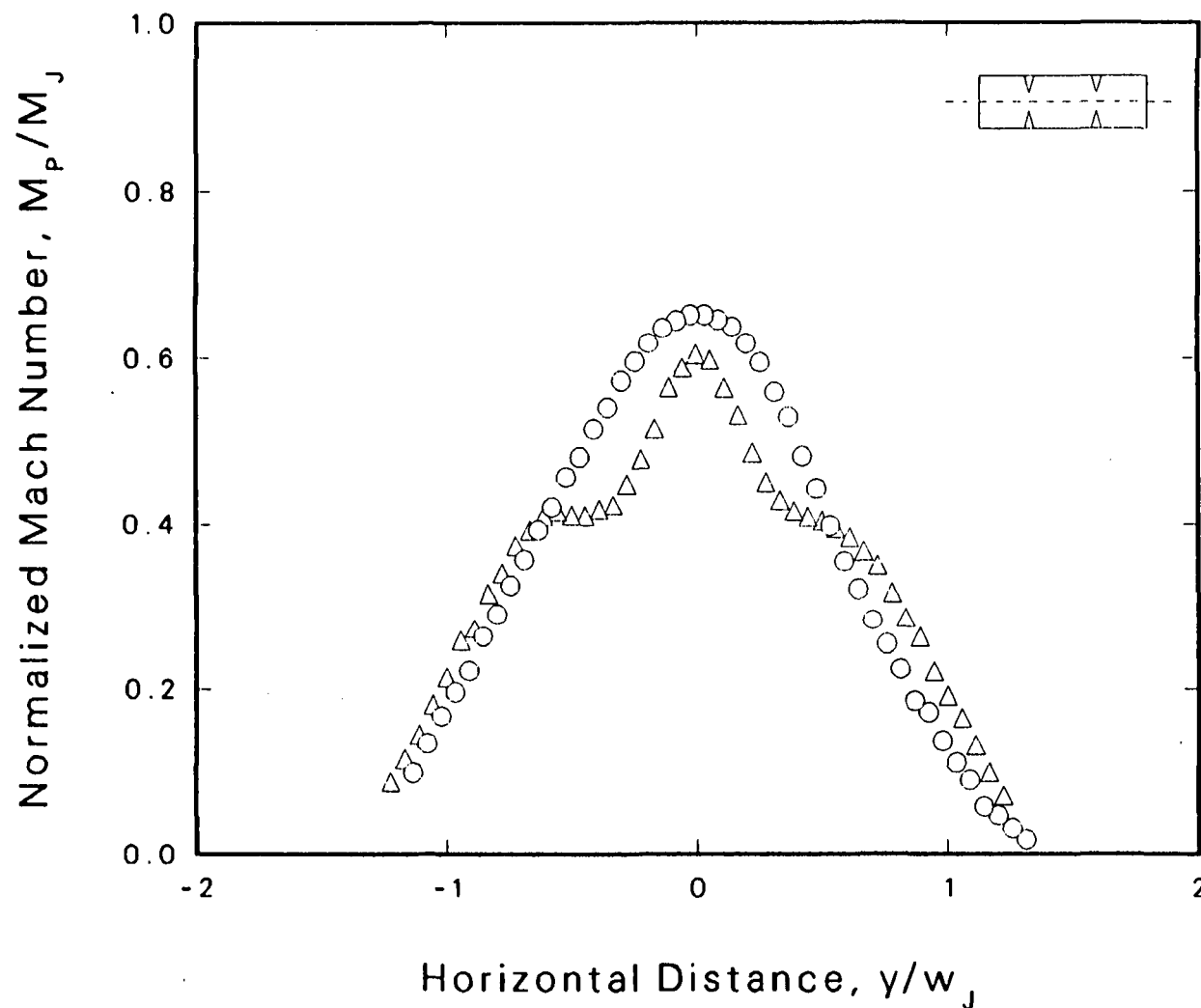
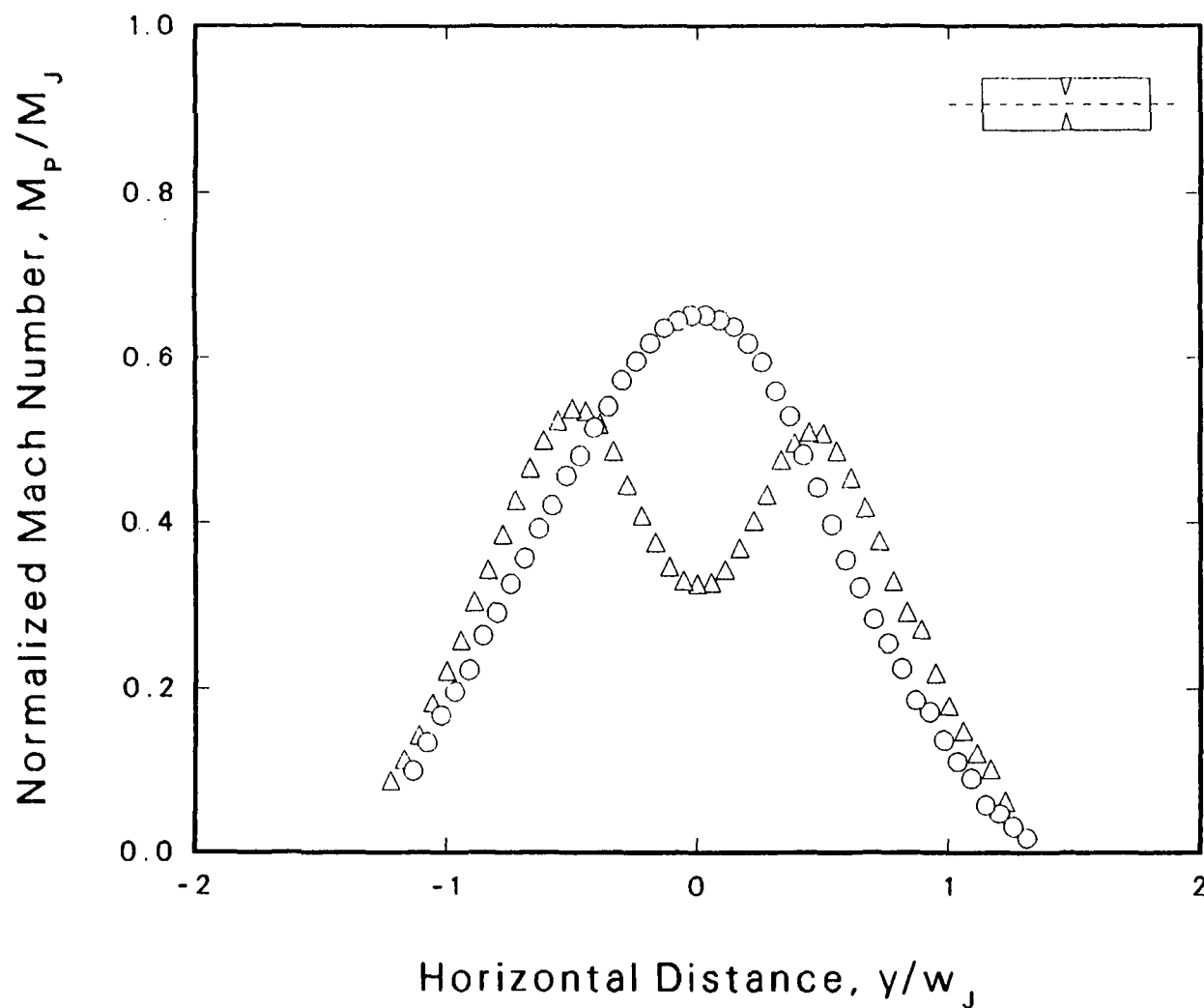


Figure 5.11 Horizontal Profile for Configuration VI-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



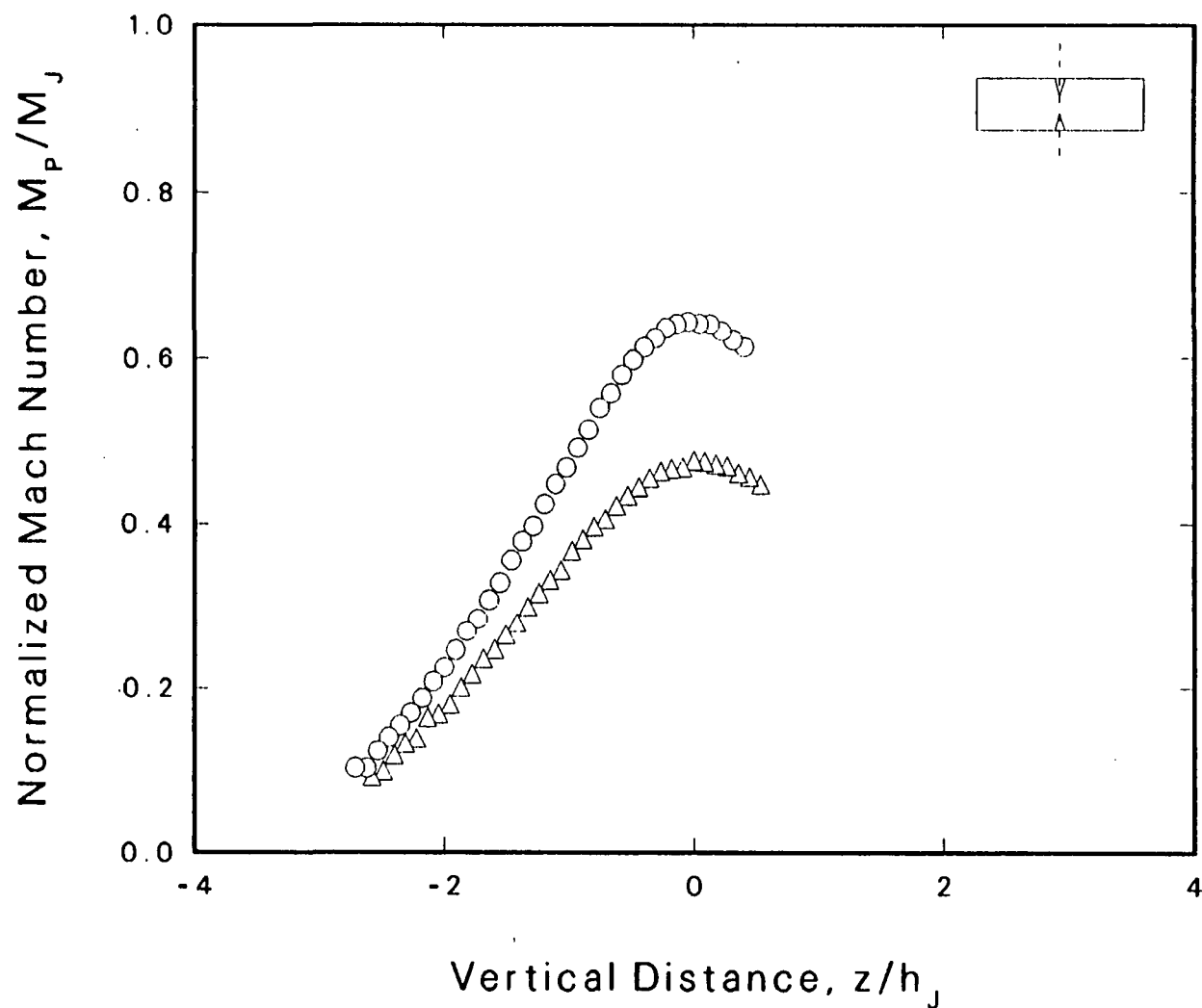
Sym	○	Δ
File	TAB147T	TAB248T
Config	0-0	VII-B
M_j	0.800	0.799
T_{TJ}/T_A	0.97	0.98
T_{TJ}, K	285.5	280.9
U_j, mps	255.2	252.8
Re_{De}	1.087	1.094
Re_h	0.482	0.485
Re_w	1.925	1.937
p_A, kPa	98.375	97.156
T_A, K	294.6	286.7
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-8.0	0.0

Figure 5.12 Horizontal Profile for Configuration VII-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



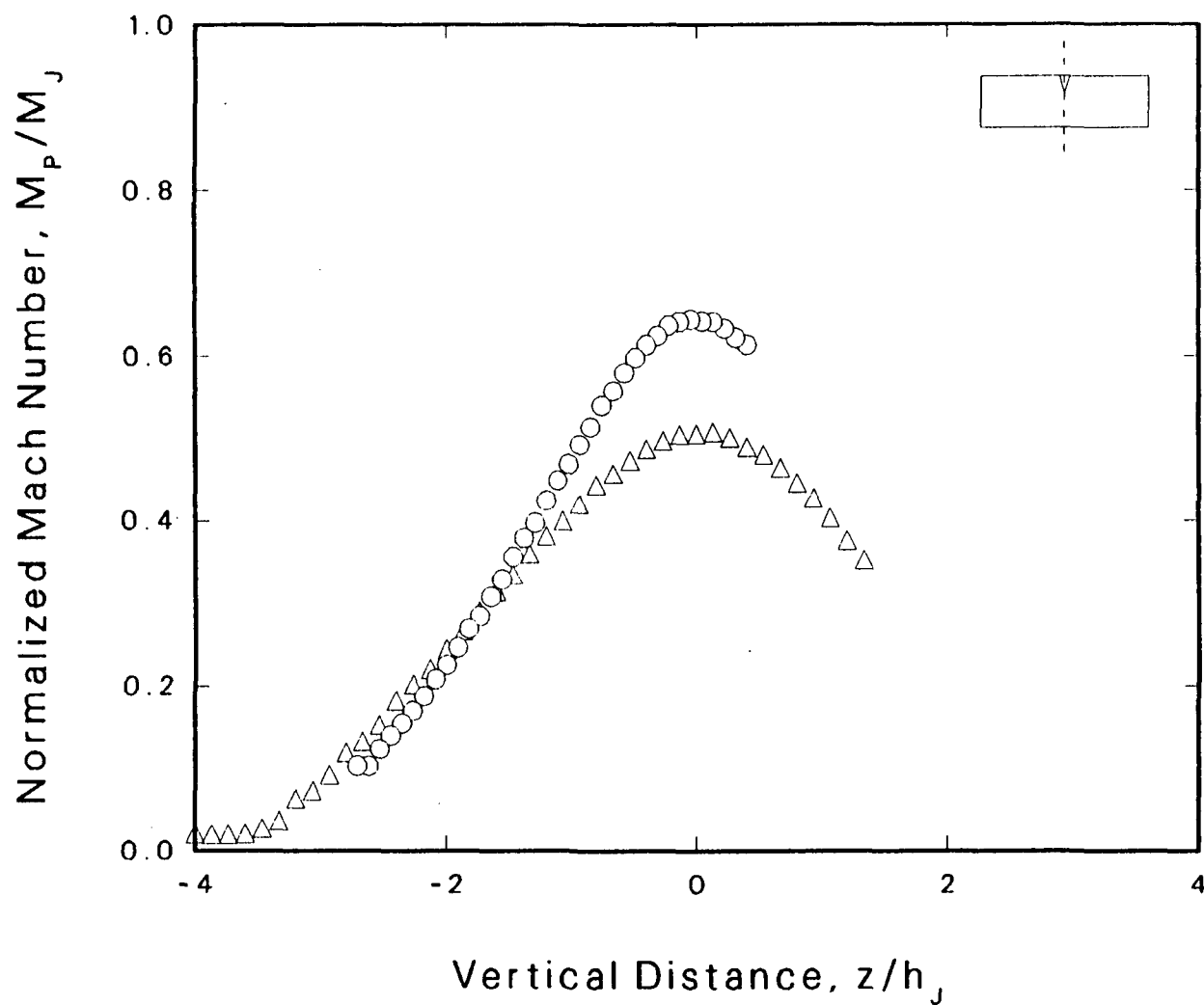
Sym	○	△
File	TAB147T	TAB365T
Config	0-0	I-C
M_j	0.800	0.797
T_{Tj}/T_A	0.97	1.00
T_{Tj}, K	285.5	282.2
U_j, mps	255.2	252.9
Re_{De}	1.087	1.105
Re_h	0.482	0.490
Re_w	1.925	1.956
p_A, kPa	98.375	98.950
T_A, K	294.6	281.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	-0.44
$\Delta Y, mm$	-8.0	0.0

Figure 5.13 Horizontal Profile for Configuration I-C
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



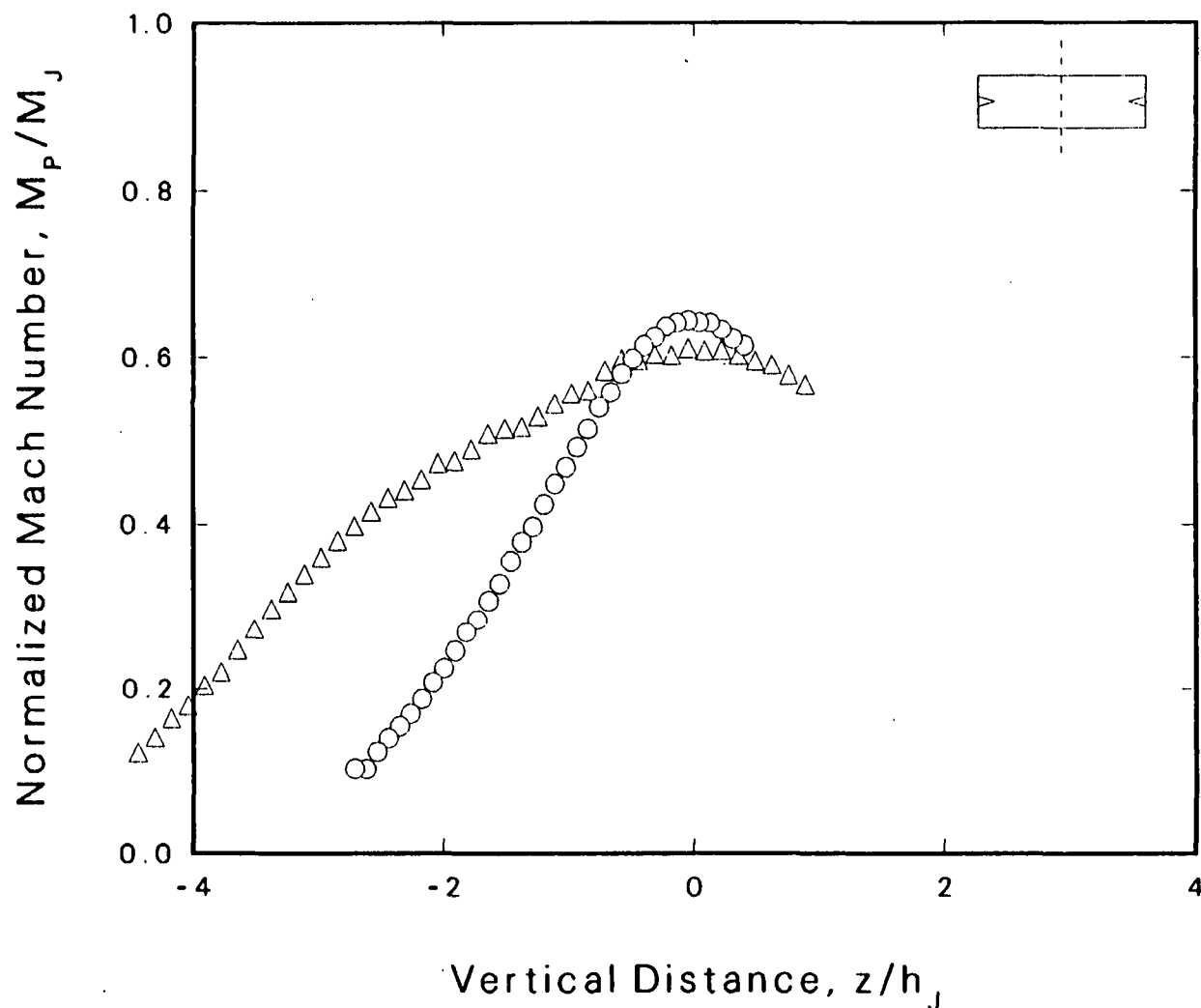
Sym	O	Δ
File	TAB146T	TAB148T
Config	0-0	I-B
M_j	0.800	0.797
T_{TJ}/T_A	0.97	0.97
T_{TJ}, K	285.8	286.3
U_j, mps	255.4	254.8
Re_{De}	1.086	1.078
Re_h	0.481	0.478
Re_w	1.922	1.909
p_A, kPa	98.375	98.341
T_A, K	294.9	294.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	-2.0

Figure 5.14 Vertical Profile for Configuration I-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



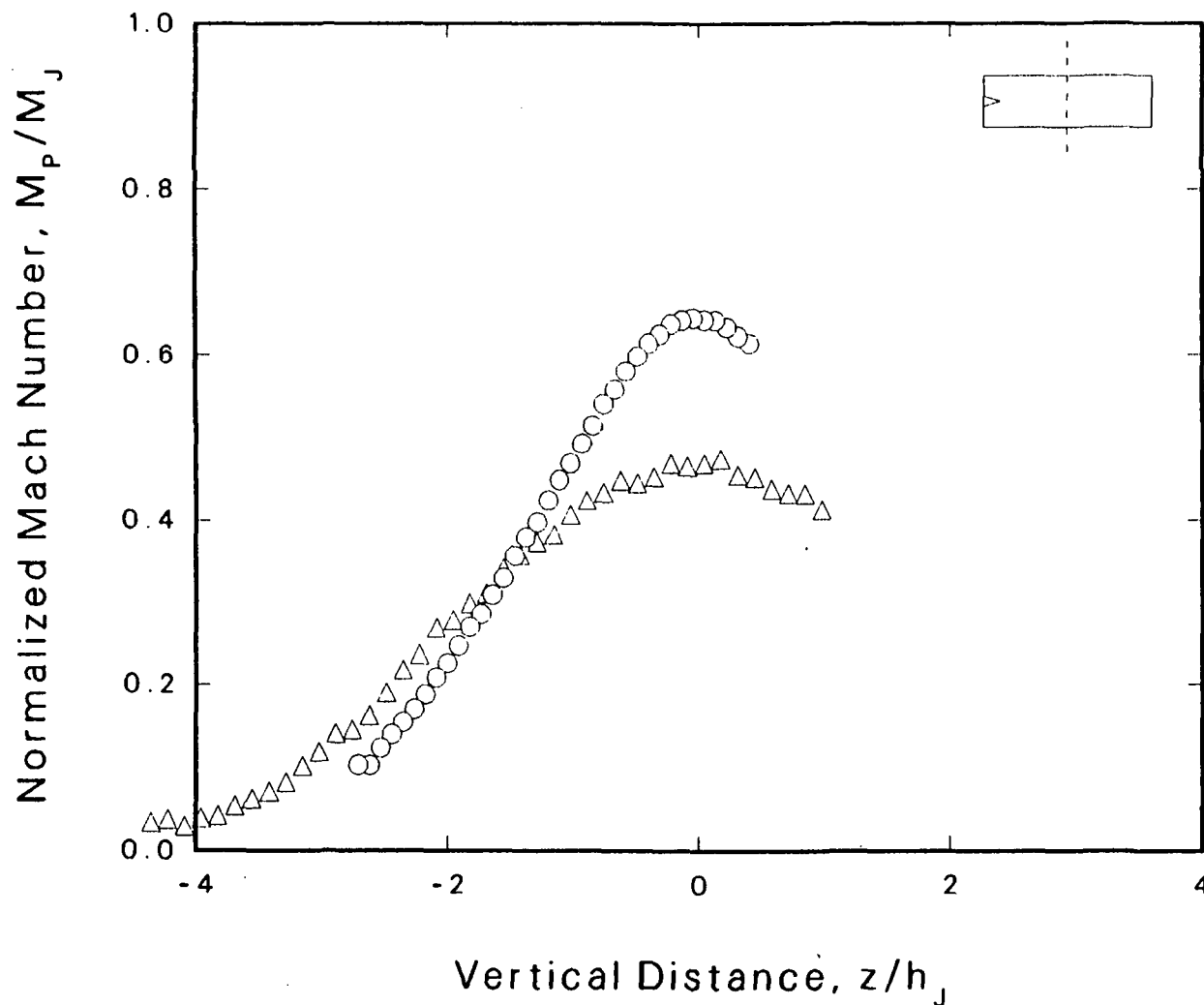
Sym	O	Δ
File	TAB146T	TAB156T
Config	0-0	III-B
M_j	0.800	0.805
T_{TJ}/T_A	0.97	0.97
T_{TJ} , K	285.8	286.0
U_j , mps	255.4	256.8
Re_{De}	1.086	1.087
Re_h	0.481	0.481
Re_w	1.922	1.924
p_A , kPa	98.375	97.799
T_A , K	294.9	295.6
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	1.0	-10.0

Figure 5.15 Vertical Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



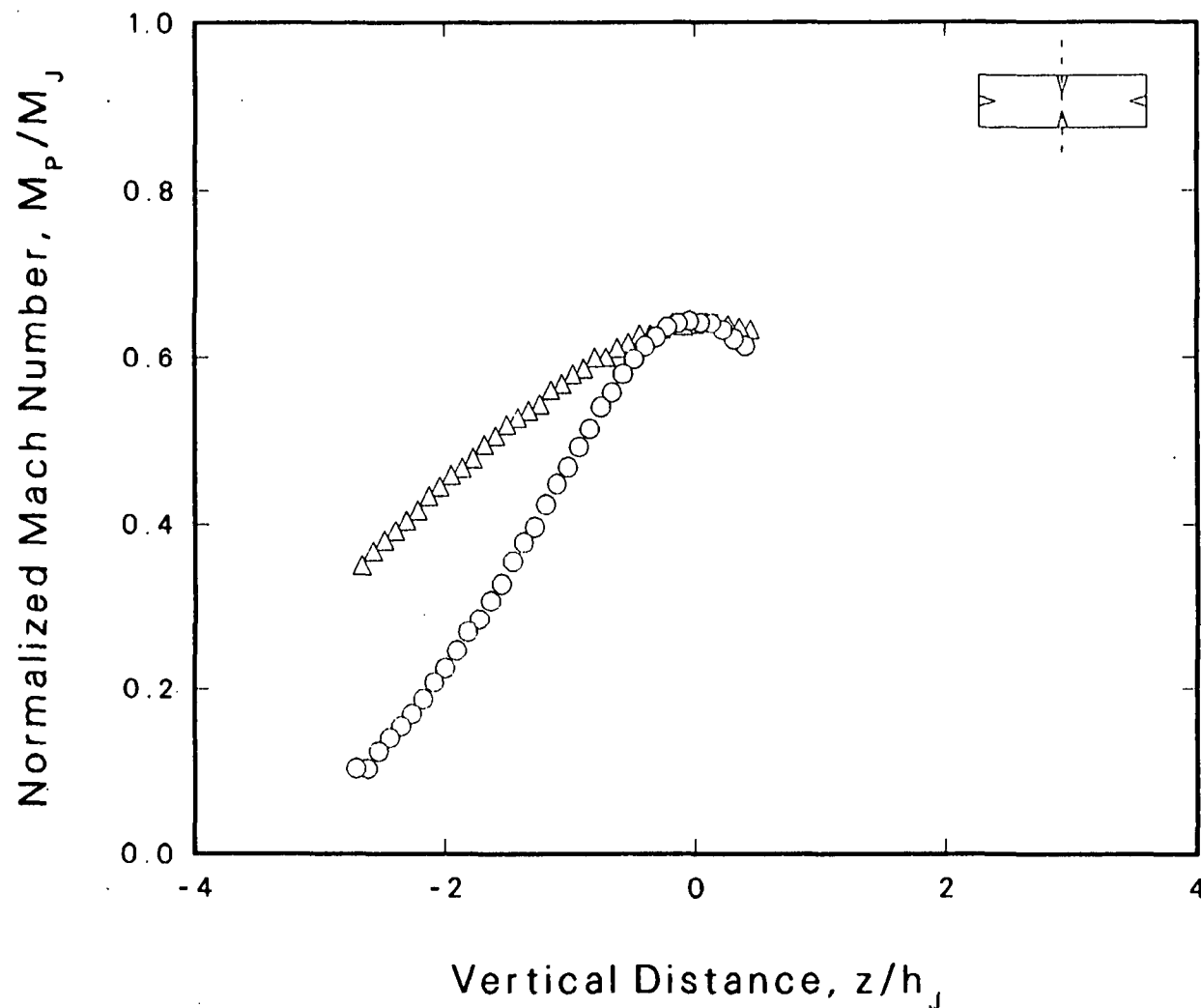
Sym	O	Δ
File	TAB146T	TAB152T
Config	0-0	II-A
M_j	0.800	0.797
T_{Tj}/T_A	0.97	0.98
T_{Tj} , K	285.8	285.3
U_j , mps	255.4	254.6
Re_{De}	1.086	1.082
Re_h	0.481	0.479
Re_w	1.922	1.915
p_A , kPa	98.375	98.171
T_A , K	294.9	289.7
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	1.0	0.0

Figure 5.16 Vertical Profile for Configuration II-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



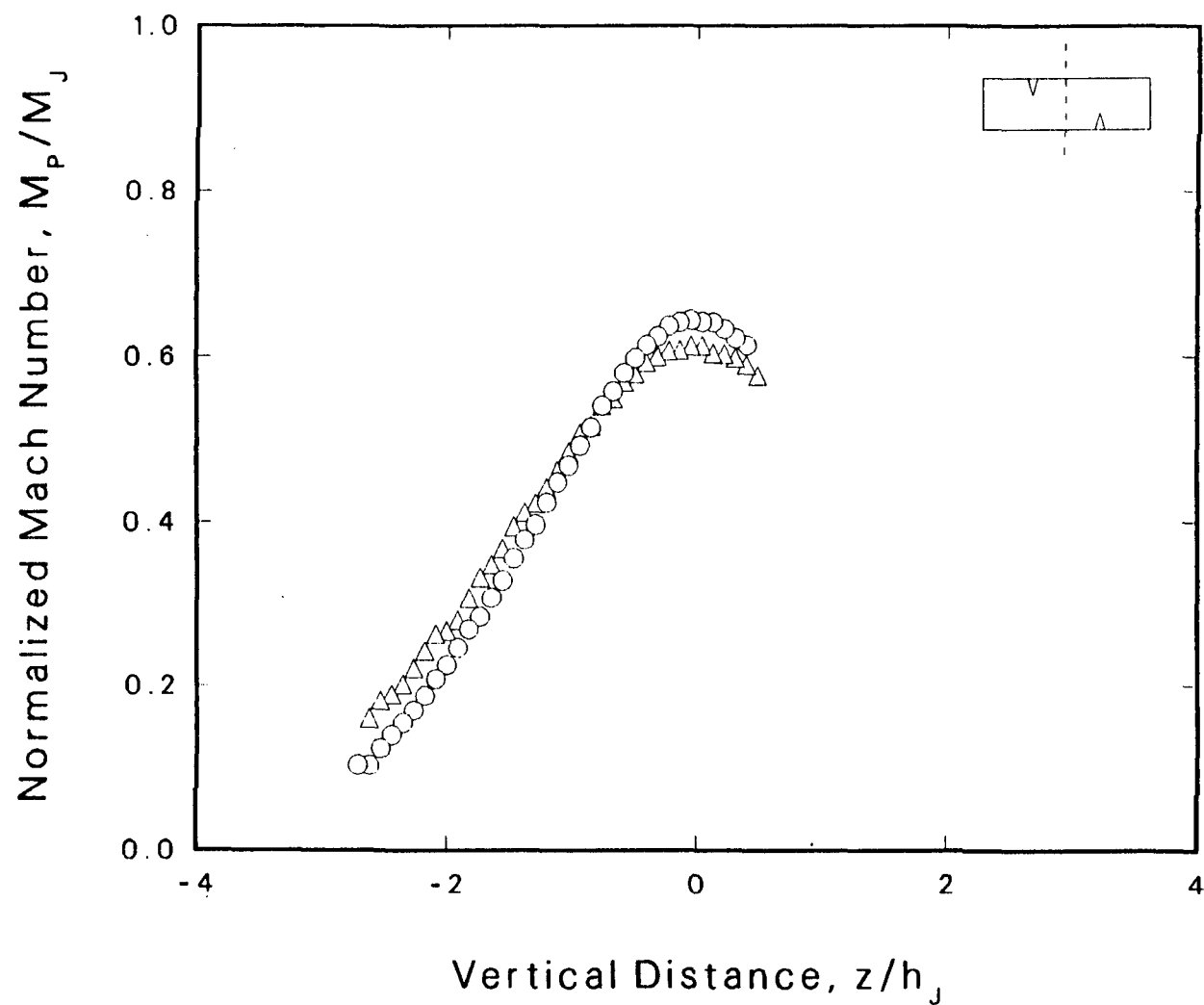
Sym	O	Δ
File	TAB146T	TAB154T
Config	0-0	IV-A
M_j	0.800	0.802
T_{Tj}/T_A	0.97	0.97
T_{Tj}, K	285.8	286.8
U_j, mps	255.4	256.3
Re_{De}	1.086	1.079
Re_h	0.481	0.478
Re_w	1.922	1.910
p_A, kPa	98.375	97.901
T_A, K	294.9	296.5
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	-2.0

Figure 5.17 Vertical Profile for Configuration IV-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



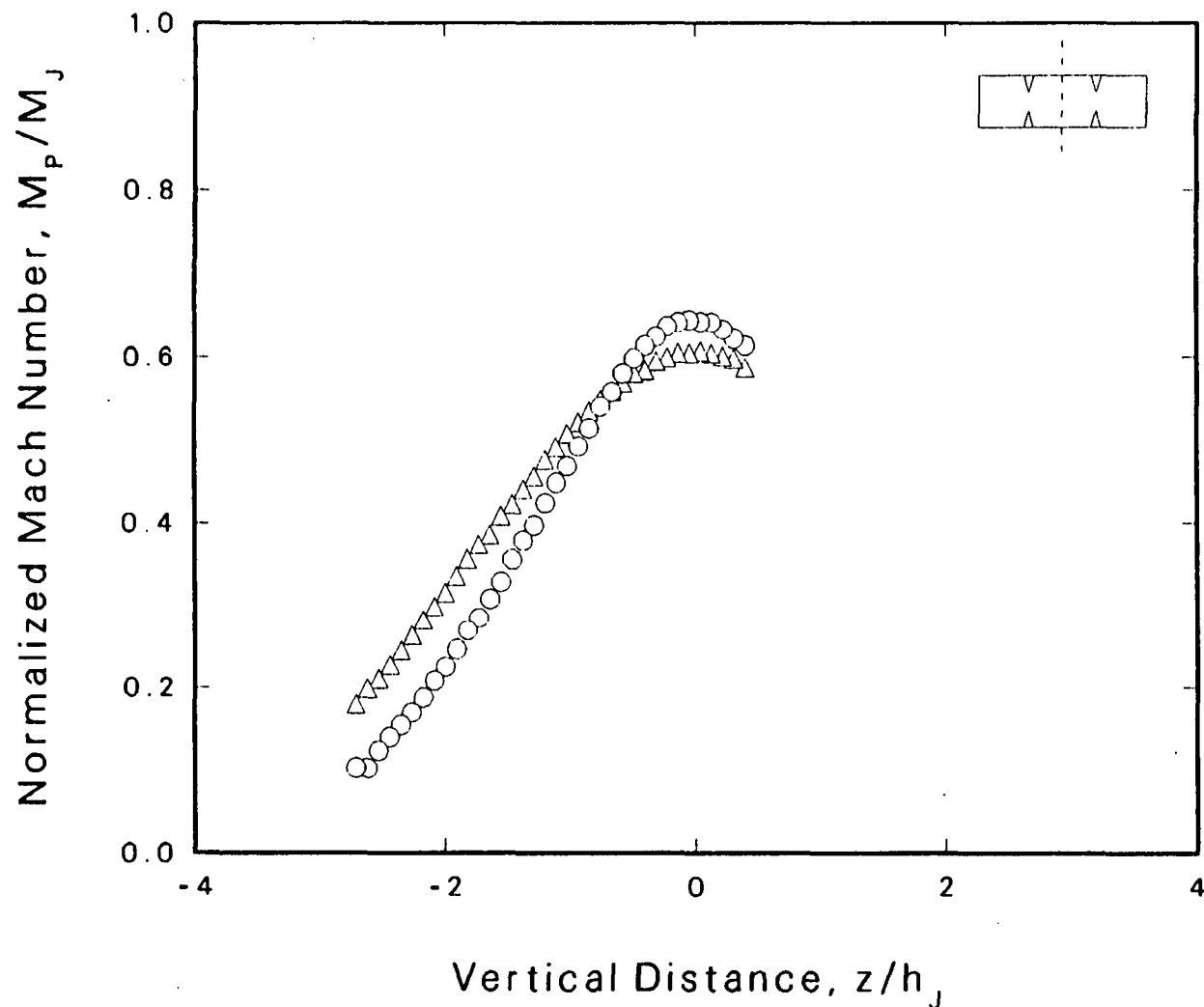
Sym	○	△
File	TAB146T	TAB276T
Config	0-0	V-C
M_j	0.800	0.799
T_{Tj}/T_A	0.97	0.98
T_{Tj} , K	285.8	279.8
U_j , mps	255.4	252.5
Re_{De}	1.086	1.115
Re_h	0.481	0.494
Re_w	1.922	1.974
p_A , kPa	98.375	98.341
T_A , K	294.9	284.6
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	1.0	0.0

Figure 5.18 Vertical Profile for Configuration V-C
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



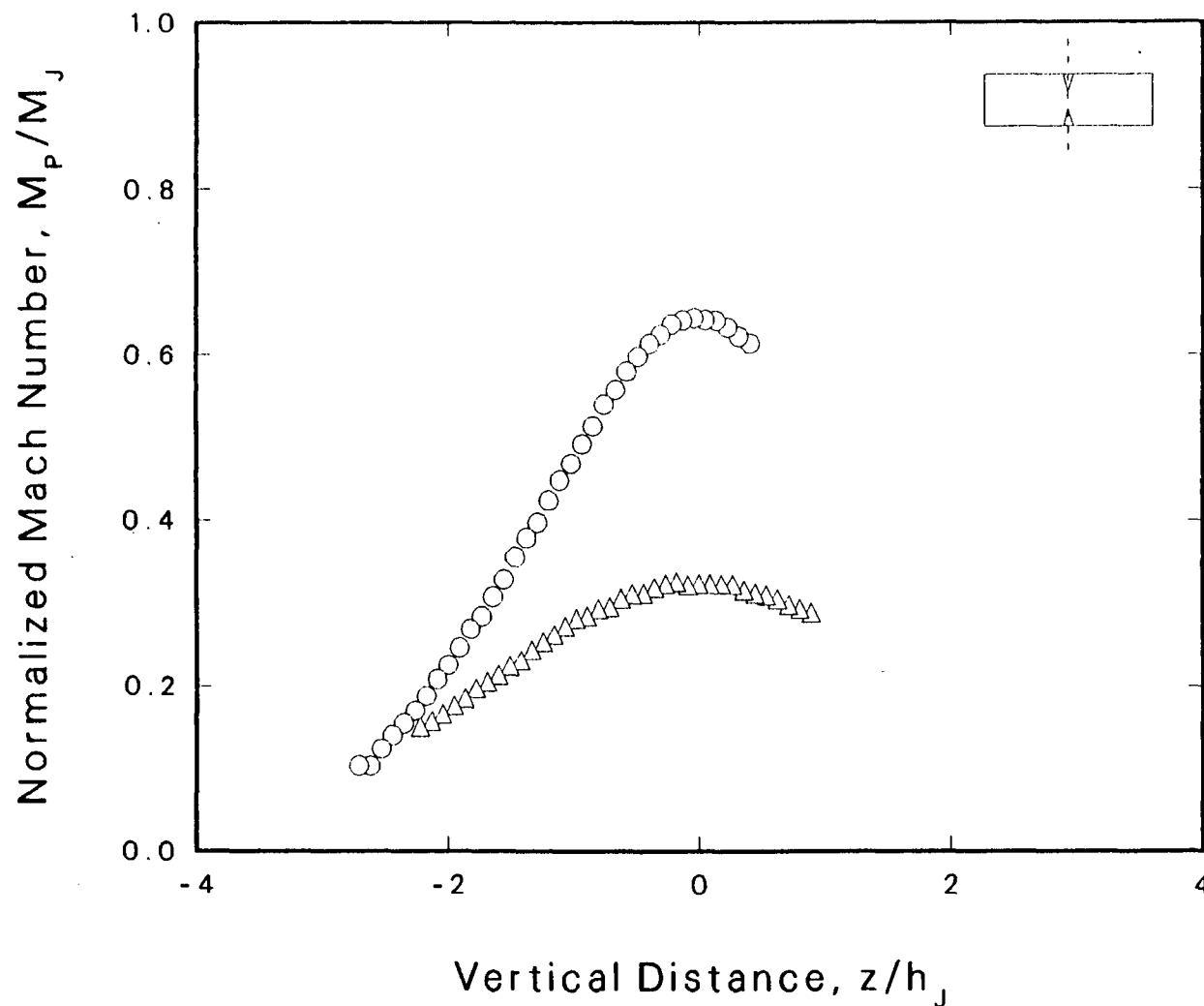
Sym	O	Δ
File	TAB146T	TAB253T
Config	0-0	VI-B
M_j	0.800	0.796
T_{TJ}/T_A	0.97	1.00
T_{TJ}, K	285.8	279.1
U_j, mps	255.4	251.3
Re_{De}	1.086	1.114
Re_h	0.481	0.494
Re_w	1.922	1.973
p_A, kPa	98.375	98.476
T_A, K	294.9	278.0
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	-1.0

Figure 5.19 Vertical Profile for Configuration VI-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



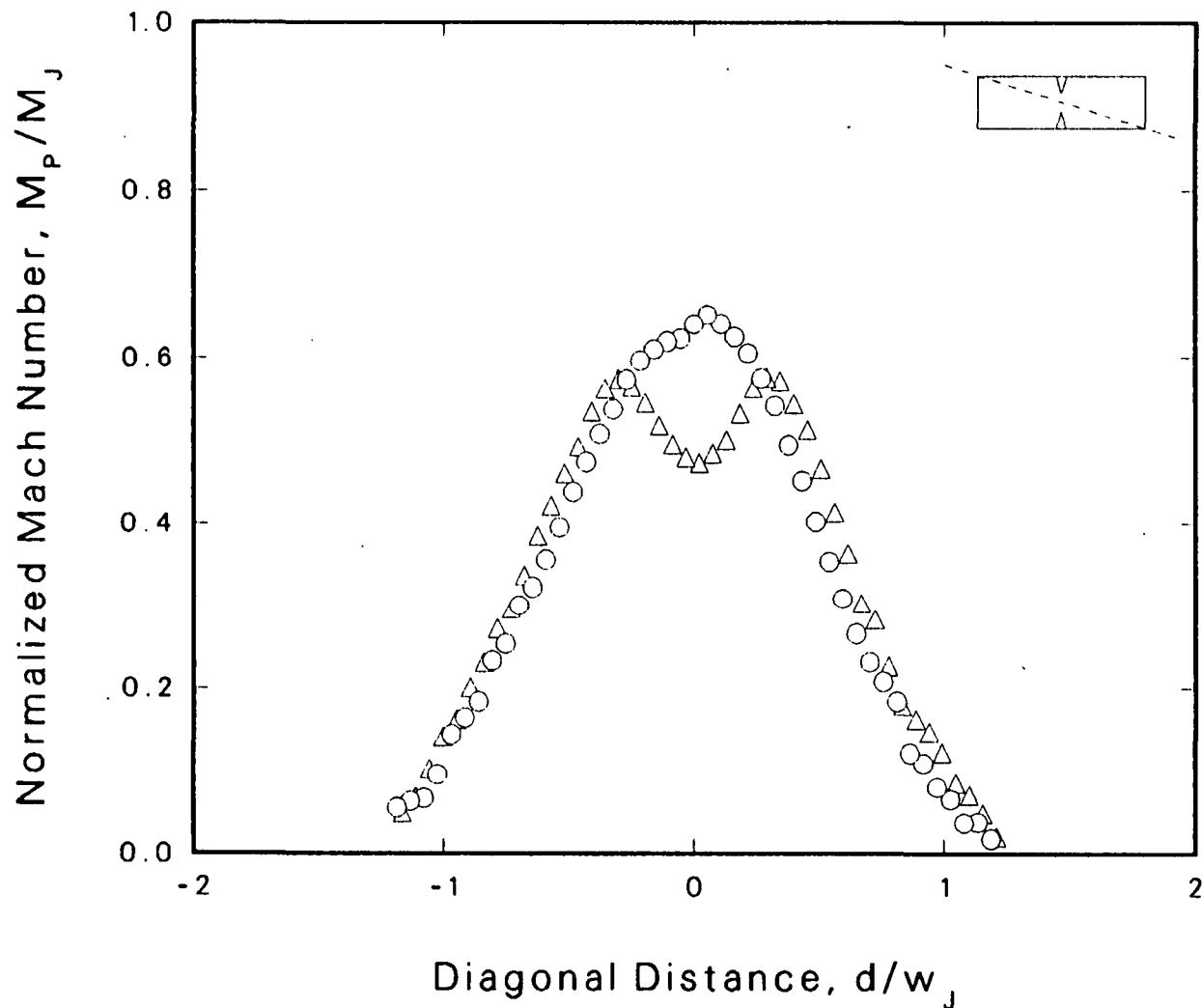
Sym	□	Δ
File	TAB146T	TAB249T
Config	0-0	VII-B
M_j	0.800	0.798
T_{Tj}/T_A	0.97	0.98
T_{Tj}, K	285.8	281.0
U_j, mps	255.4	252.7
Re_{De}	1.086	1.094
Re_h	0.481	0.484
Re_w	1.922	1.936
p_A, kPa	98.375	97.189
T_A, K	294.9	286.9
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	1.0

Figure 5.20 Vertical Profile for Configuration VII-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



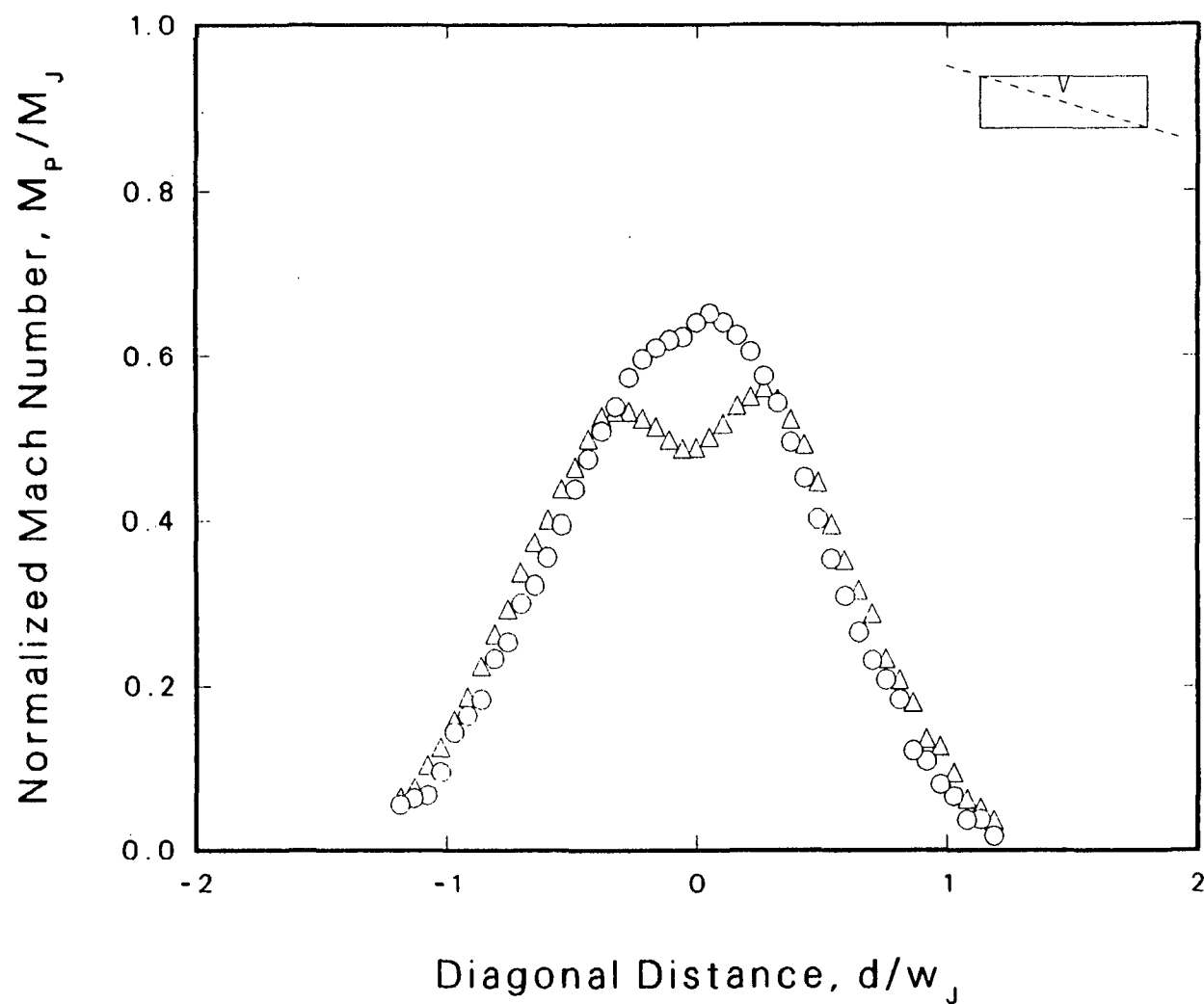
Sym	O	Δ
File	TAB146T	TAB364T
Config	0-0	I-C
M_j	0.800	0.797
T_{Tj}/T_A	0.97	1.01
T_{Tj}, K	285.8	281.8
U_j, mps	255.4	252.8
Re_{De}	1.086	1.108
Re_h	0.481	0.491
Re_w	1.922	1.960
p_A, kPa	98.375	98.916
T_A, K	294.9	280.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	-10.0

Figure 5.21 Vertical Profile for Configuration I-C
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



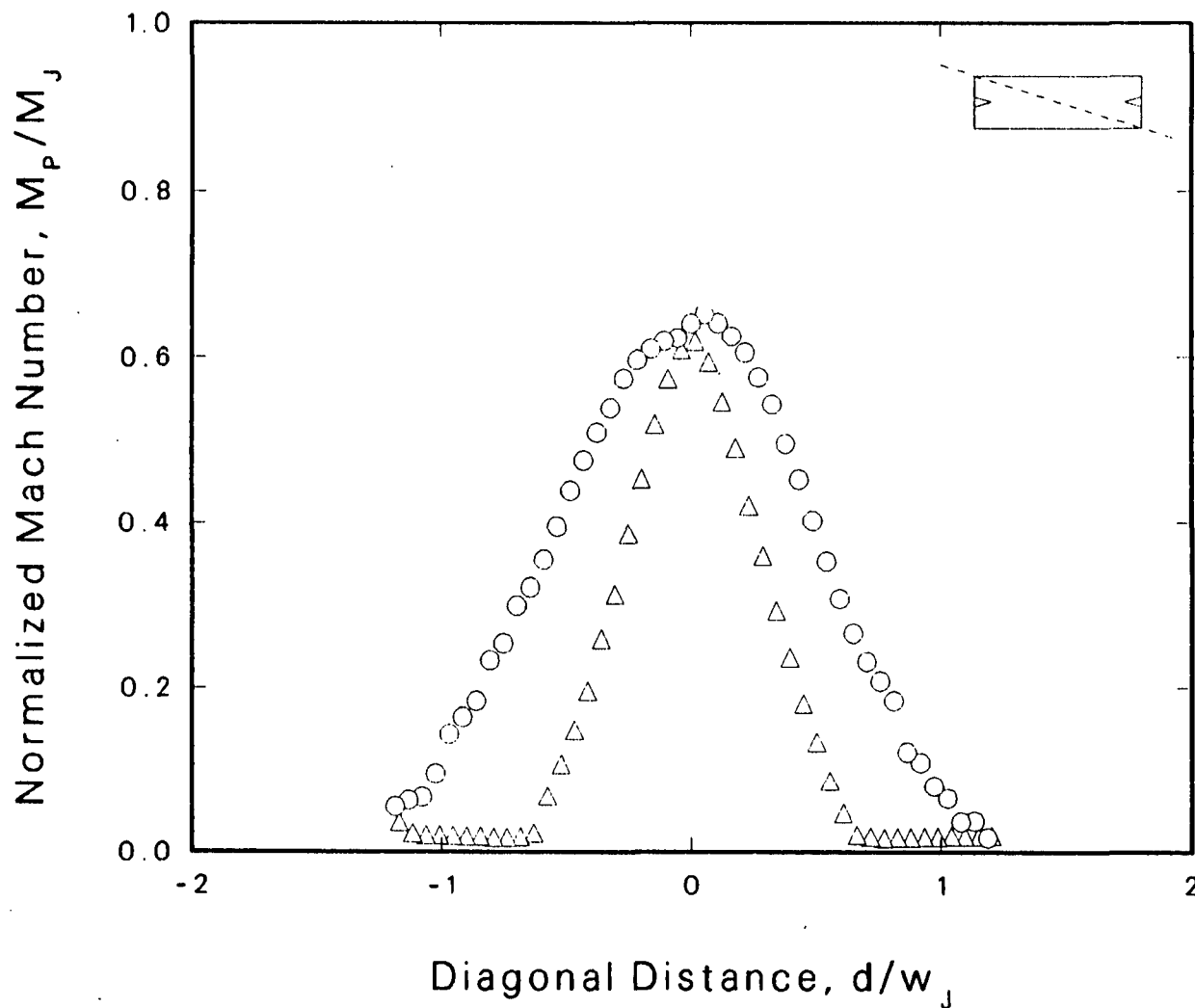
Sym	○	Δ
File	TAB165T	TAB167T
Config	0-0	I-B
M_j	0.797	0.797
T_{TJ}/T_A	0.98	1.00
T_{TJ}, K	285.1	283.8
U_j, mps	254.3	253.7
Re_{De}	1.088	1.092
Re_h	0.482	0.484
Re_w	1.985	1.992
p_A, kPa	98.713	98.442
T_A, K	290.6	282.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-2.0

Figure 5.22 Diagonal Profile for Configuration I-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.



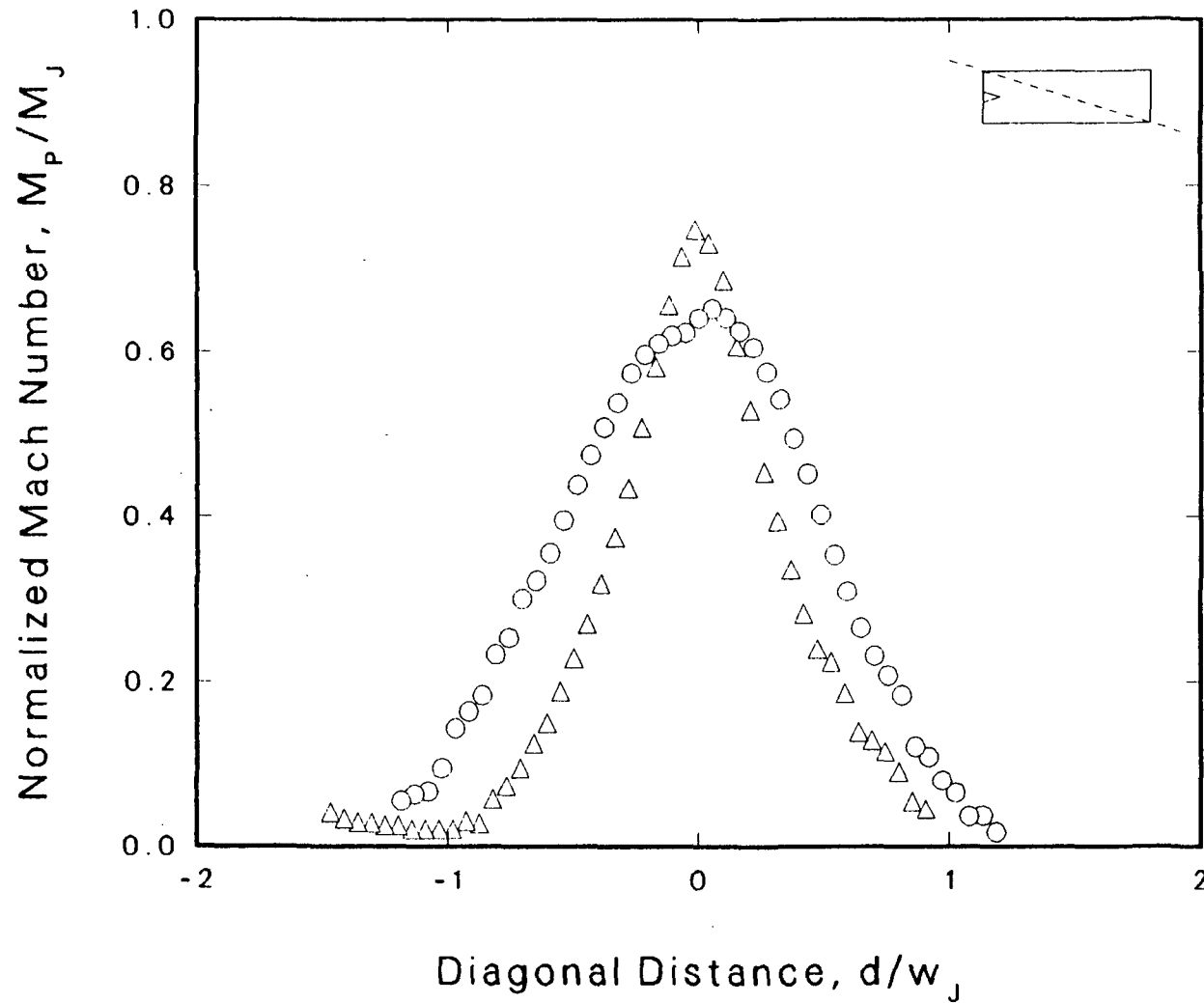
Sym	O	Δ
File	TAB165T	TAB170T
Config	0-0	III-B
M_j	0.797	0.799
T_{Tj}/T_A	0.98	0.98
T_{Tj}, K	285.1	284.9
U_j, mps	254.3	254.7
Re_{De}	1.088	1.087
Re_h	0.482	0.481
Re_w	1.985	1.983
p_A, kPa	98.713	98.239
T_A, K	290.6	289.5
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 5.23 Diagonal Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.



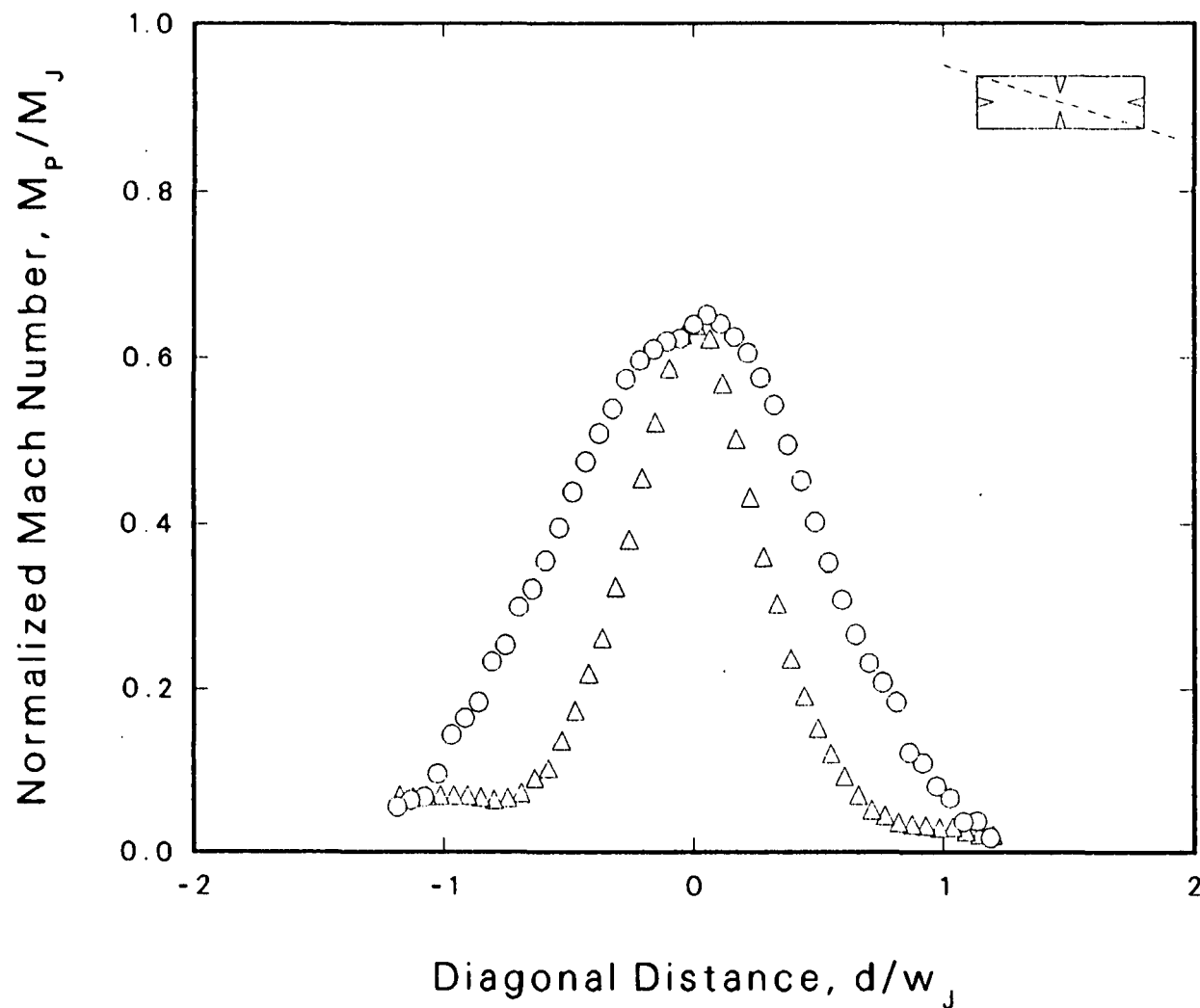
Sym	O	Δ
File	TAB165T	TAB171T
Config	0-0	II-A
M_j	0.797	0.799
T_{TJ}/T_A	0.98	0.98
T_{TJ}, K	285.1	284.9
U_j, mps	254.3	254.6
Re_{De}	1.088	1.086
Re_h	0.482	0.481
Re_w	1.985	1.982
p_A, kPa	98.713	98.205
T_A, K	290.6	289.3
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.5

Figure 5.24 Diagonal Profile for Configuration II-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.



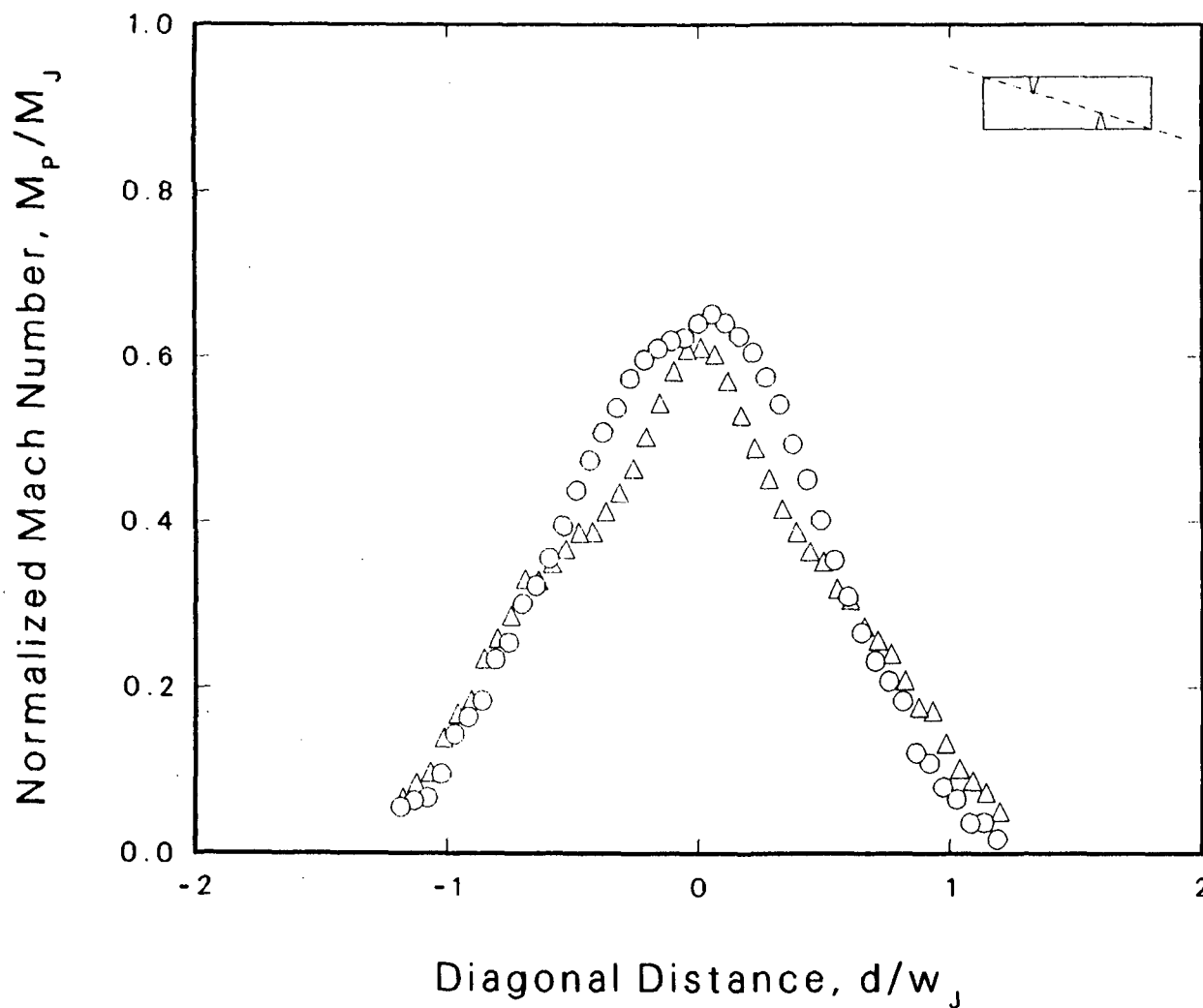
Sym	○	△
File	TAB165T	TAB172T
Config	0-0	IV-A
M_j	0.797	0.798
T_{Tj}/T_A	0.98	0.99
T_{Tj}, K	285.1	284.5
U_j, mps	254.3	254.3
Re_{De}	1.088	1.087
Re_h	0.482	0.481
Re_w	1.985	1.983
p_A, kPa	98.713	98.171
T_A, K	290.6	288.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	26.0

Figure 5.25 Diagonal Profile for Configuration IV-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.



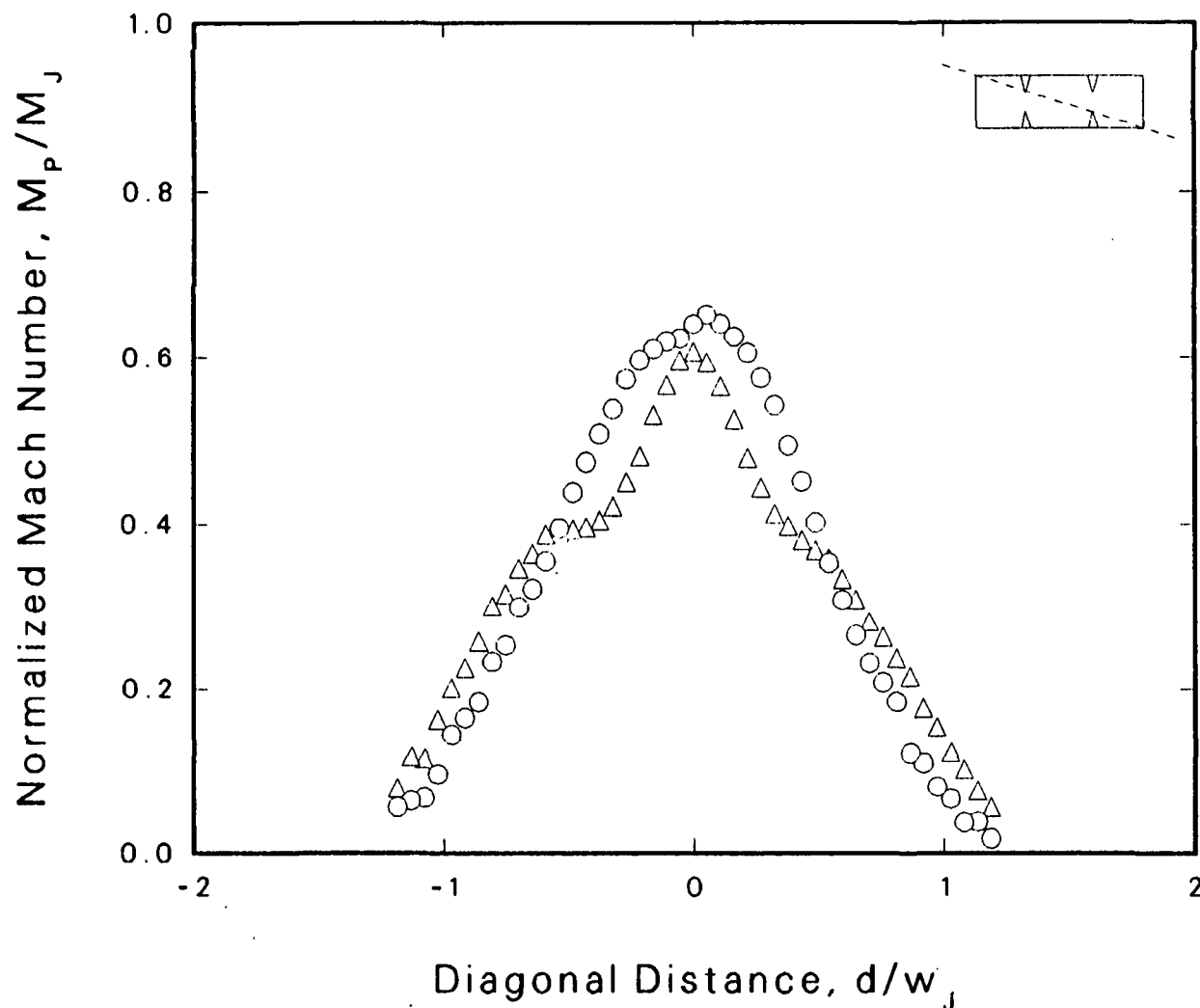
Sym	○	△
File	TAB165T	TAB260T
Config	0-0	V-C
M_j	0.797	0.797
T_{TJ}/T_A	0.98	1.00
T_{TJ}, K	285.1	279.5
U_j, mps	254.3	251.9
Re_{De}	1.088	1.119
Re_h	0.482	0.496
Re_w	1.985	2.041
p_A, kPa	98.713	98.815
T_A, K	290.6	278.4
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.26 Diagonal Profile for Configuration V-C
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.



Sym	O	Δ
File	TAB165T	TAB264T
Config	0-0	VI-B
M_j	0.797	0.797
T_{Tj}/T_A	0.98	1.01
T_{Tj}, K	285.1	278.9
U_j, mps	254.3	251.4
Re_{De}	1.088	1.119
Re_h	0.482	0.495
Re_w	1.985	2.041
p_A, kPa	98.713	98.612
T_A, K	290.6	276.4
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.27 Diagonal Profile for Configuration VI-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.



Sym	O	Δ
File	TAB165T	TAB261T
Config	0-0	VII-B
M_j	0.797	0.797
T_{Tj}/T_A	0.98	0.99
T_{Tj} , K	285.1	280.4
U_j , mps	254.3	252.2
Re_{De}	1.088	1.114
Re_h	0.482	0.493
Re_w	1.985	2.032
p_A , kPa	98.713	98.883
T_A , K	290.6	281.9
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	0.0	0.0

Figure 5.28 Diagonal Profile for Configuration VII-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, -14 deg.

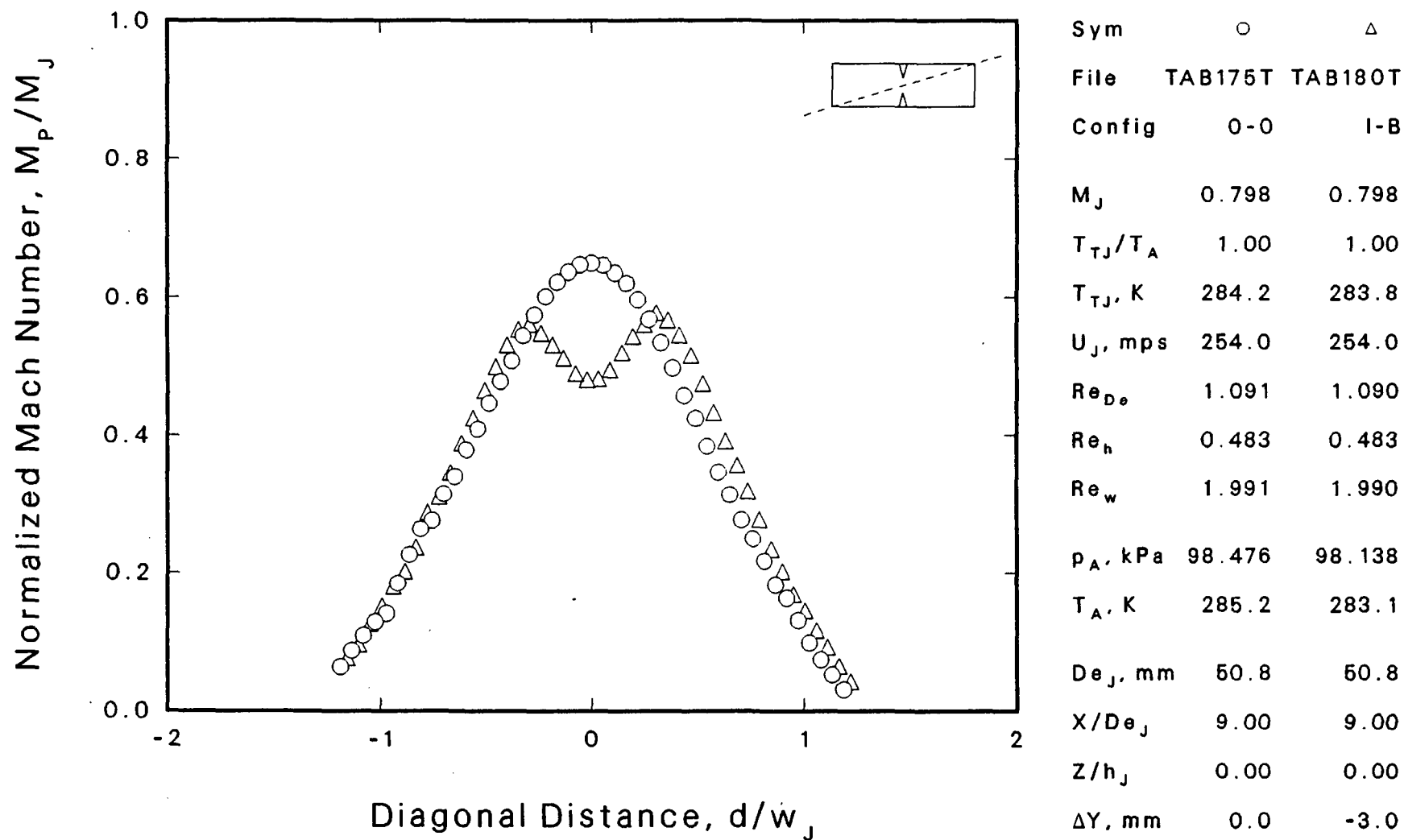
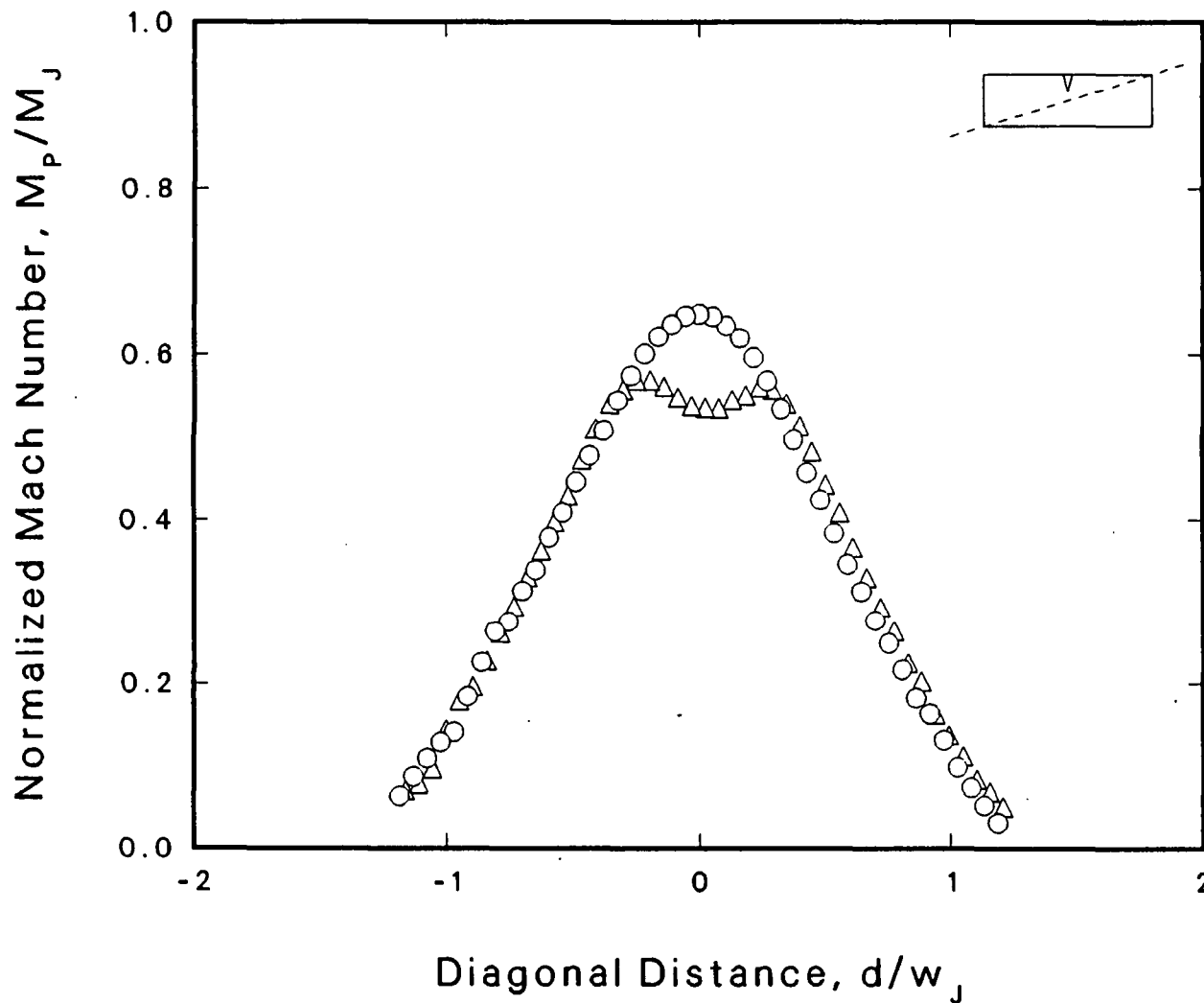


Figure 5.29 Diagonal Profile for Configuration I-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.



Sym	O	Δ
File	TAB175T	TAB181T
Config	0-0	III-B
M_j	0.798	0.799
T_{Tj}/T_A	1.00	1.00
T_{Tj}, K	284.2	283.9
U_j, mps	254.0	254.2
Re_{De}	1.091	1.091
Re_h	0.483	0.483
Re_w	1.991	1.990
p_A, kPa	98.476	98.138
T_A, K	285.2	283.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-2.0

Figure 5.30 Diagonal Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.

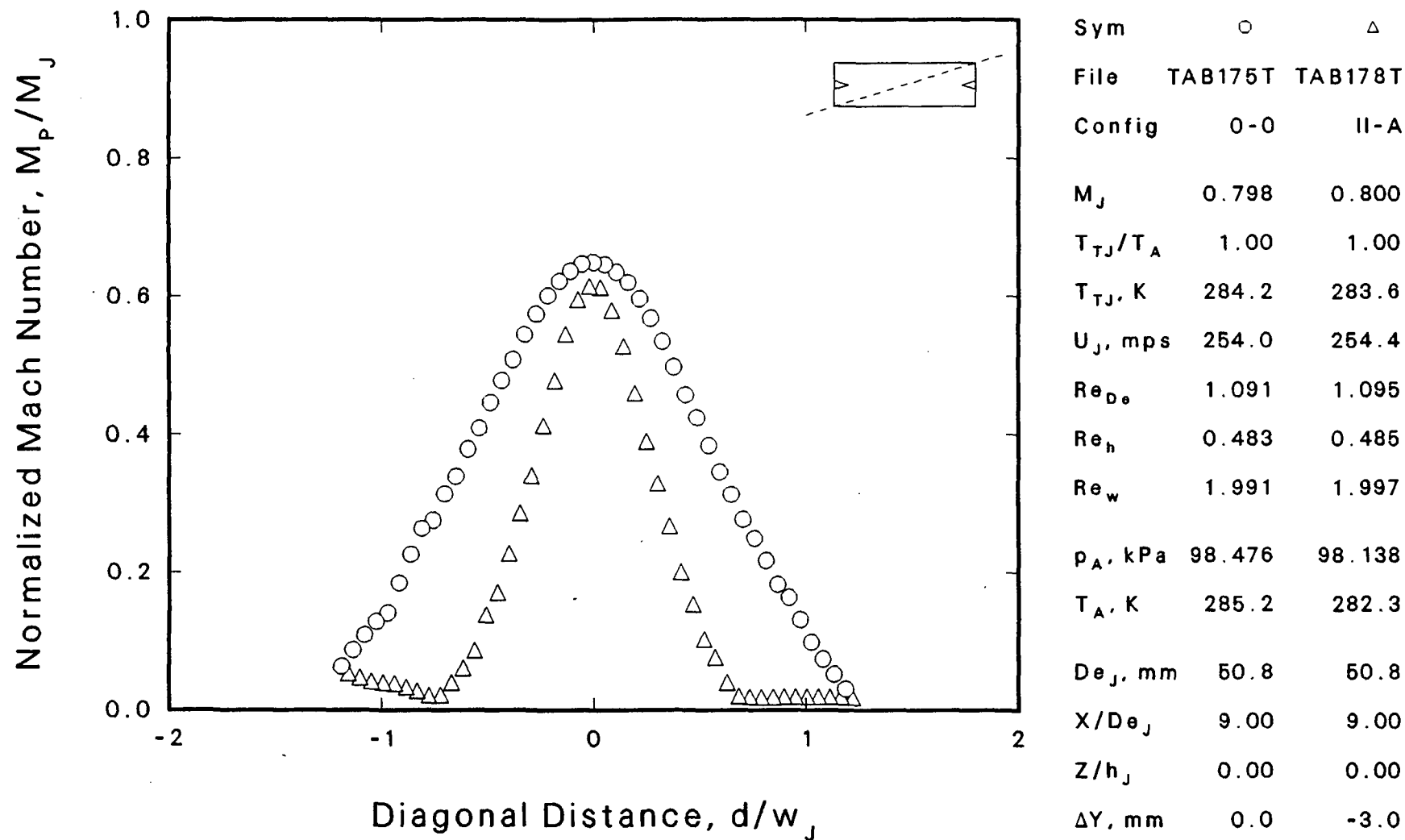
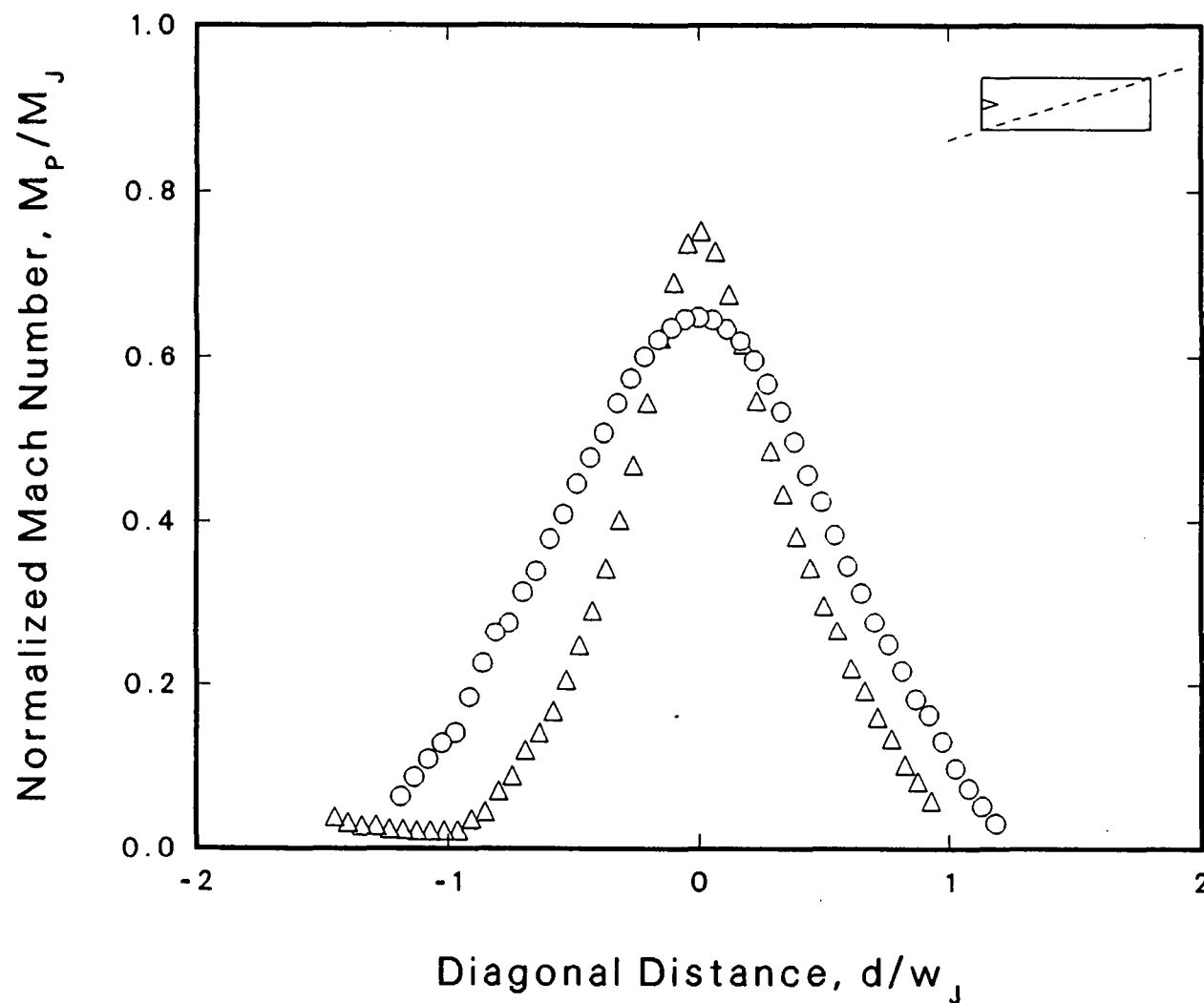


Figure 5.31 Diagonal Profile for Configuration II-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.



Sym	○	Δ
File	TAB175T	TAB179T
Config	0-0	IV-A
M_j	0.798	0.800
T_{Tj}/T_A	1.00	1.01
T_{Tj}, K	284.2	283.8
U_j, mps	254.0	254.4
Re_{De}	1.091	1.093
Re_h	0.483	0.484
Re_w	1.991	1.993
p_A, kPa	98.476	98.138
T_A, K	285.2	282.2
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	24.0

Figure 5.32 Diagonal Profile for Configuration IV-A
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.

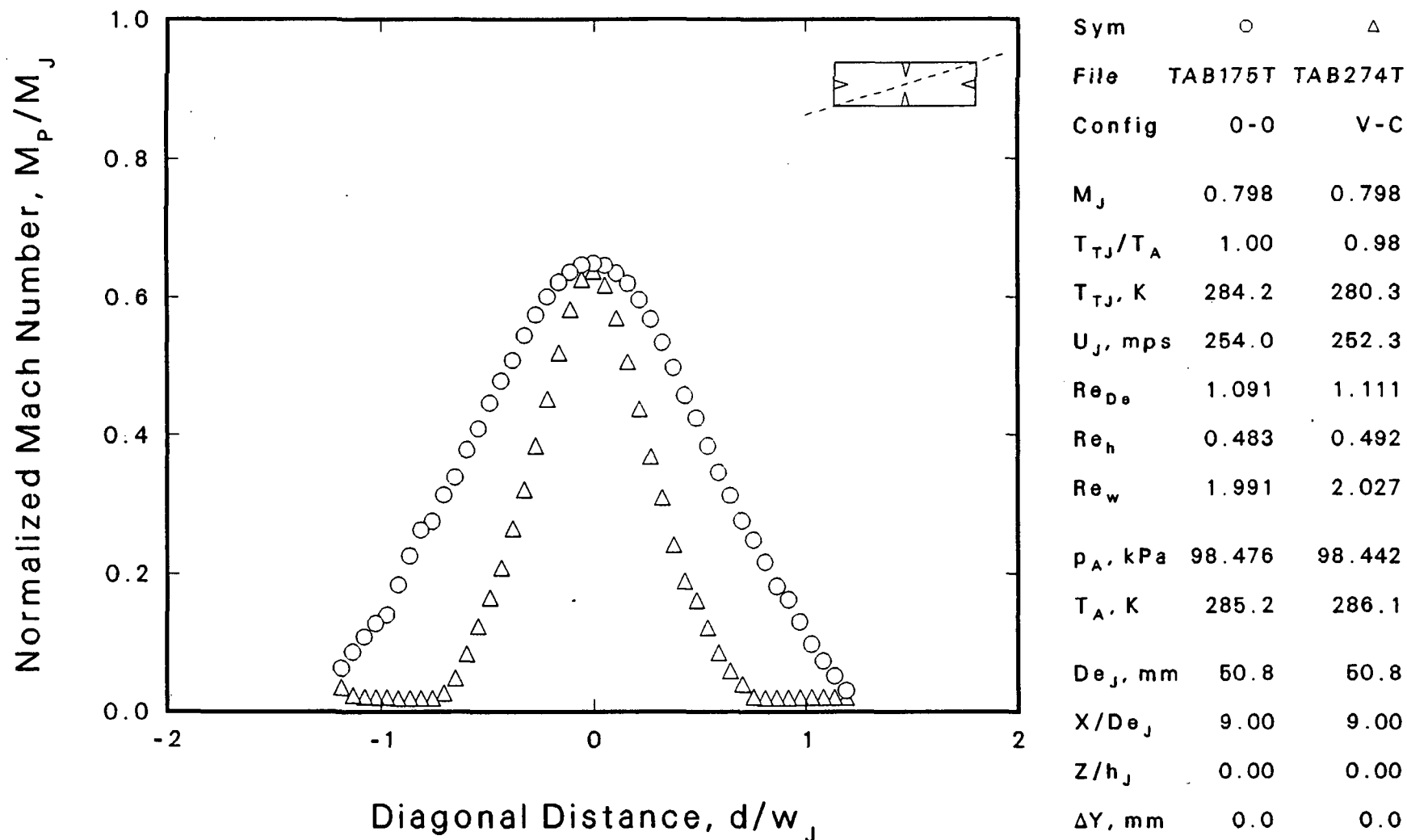
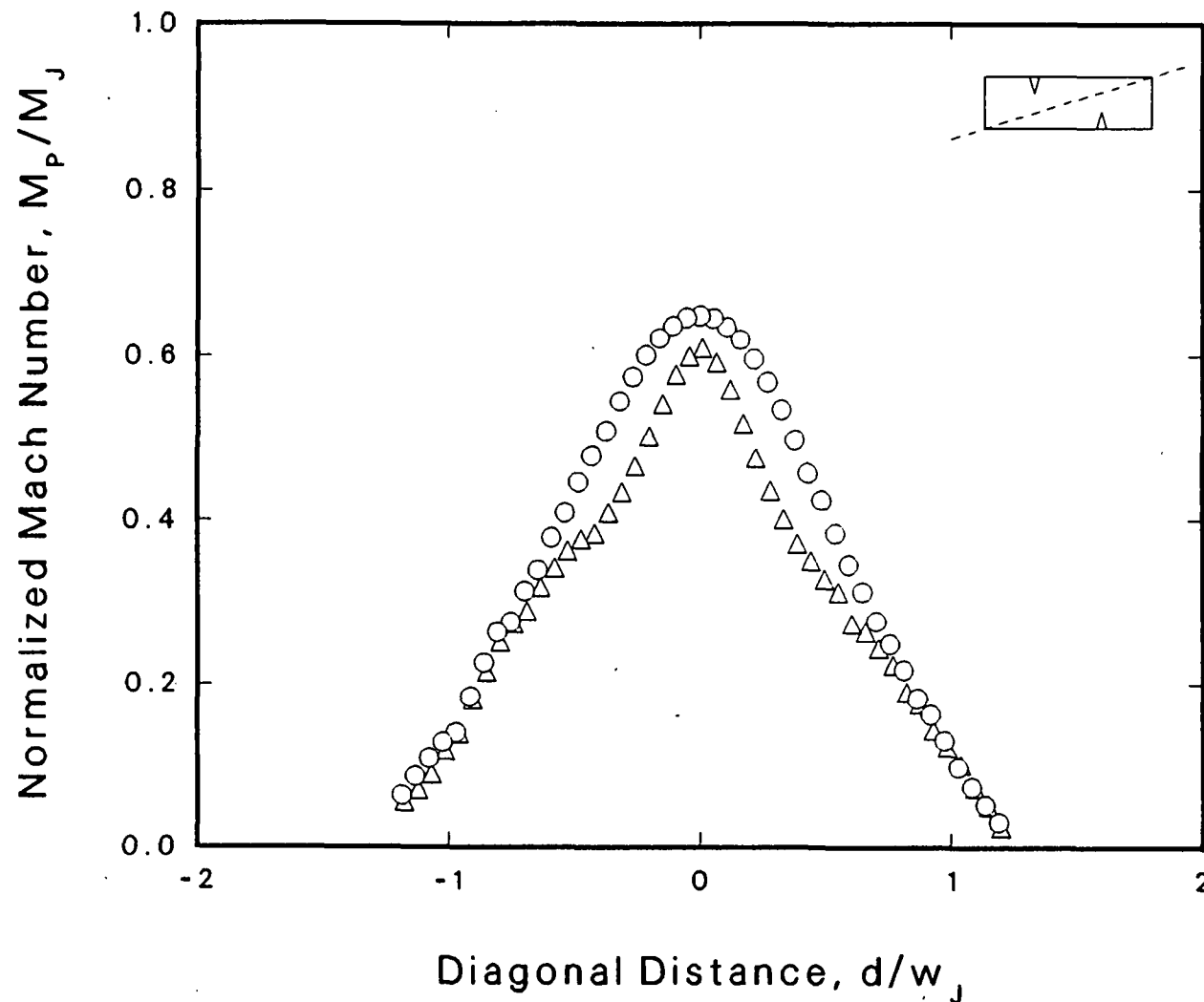


Figure 5.33 Diagonal Profile for Configuration V-C
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.



Sym	○	Δ
File	TAB176T	TAB273T
Config	0-0	VI-B
M_j	0.798	0.797
T_{Tj}/T_A	1.00	0.99
T_{Tj} , K	284.2	279.9
U_j , mps	254.0	252.0
Re_{D_0}	1.091	1.114
Re_h	0.483	0.493
Re_w	1.991	2.032
p_A , kPa	98.476	98.612
T_A , K	285.2	283.8
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	0.0	-1.0

Figure 5.34 Diagonal Profile for Configuration VI-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.

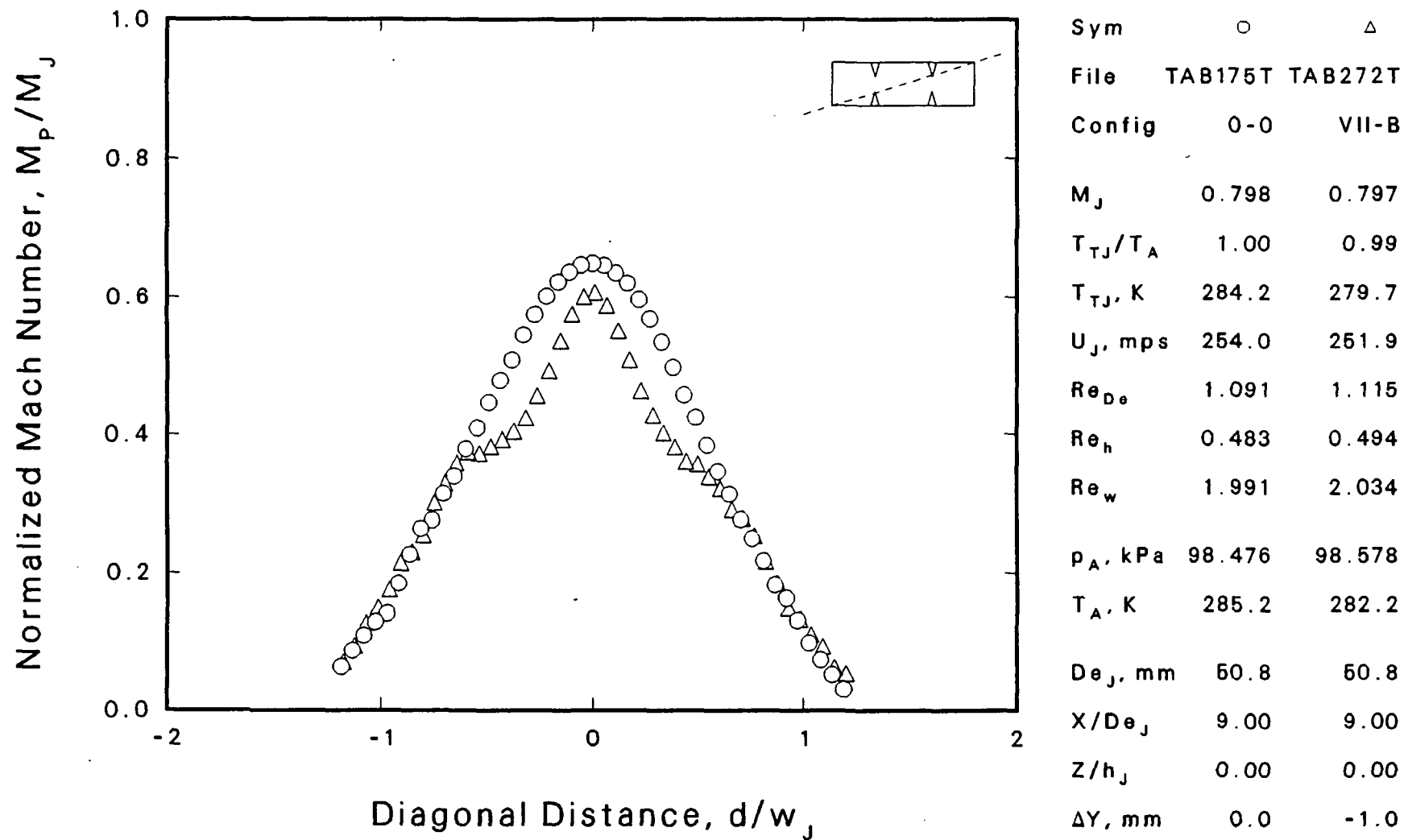


Figure 5.35 Diagonal Profile for Configuration VII-B
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, +14 deg.

- (4) Data for configuration V-C (See Figures 5.10, 5.26 and 5.33) appears to have significantly narrowed down the cross-section of the jet at $X/D_e = 9$. It appears, however, that mass flow rate may be constrained because of the large tabs used here.
- (5) In general, configurations with tabs aligned along the minor axis appear to be better performers than those with tabs aligned along the major axis of the rectangular jet. Tabs along the minor axis mostly provided velocity profiles that were depressed around the centerline. Tabs aligned along the major axis produced a bulge in the middle of the velocity profile. This observation lead to configuration V-C, which was an attempt to improve the performance of the horizontal tab configuration by using the vertical centerline tabs to counter the tendency of the profile to bulge in the middle. The resultant mixing was no better than that of the baseline nozzle.
- (6) Data from many of the configurations, (e.g., V-C, II-A) indicate that the tabs pinch the jet in one direction and cause it to expand in another. For example, the data for configuration V-C in Figure 5.10 shows that the cross-section of the jet at $X/D_e = 9$ has reduced considerably along the major axis, while the data for the same configuration in Figure 5.18 shows that the jet has spread out in the minor axis direction.

5.3.2 Effect of Tab Size

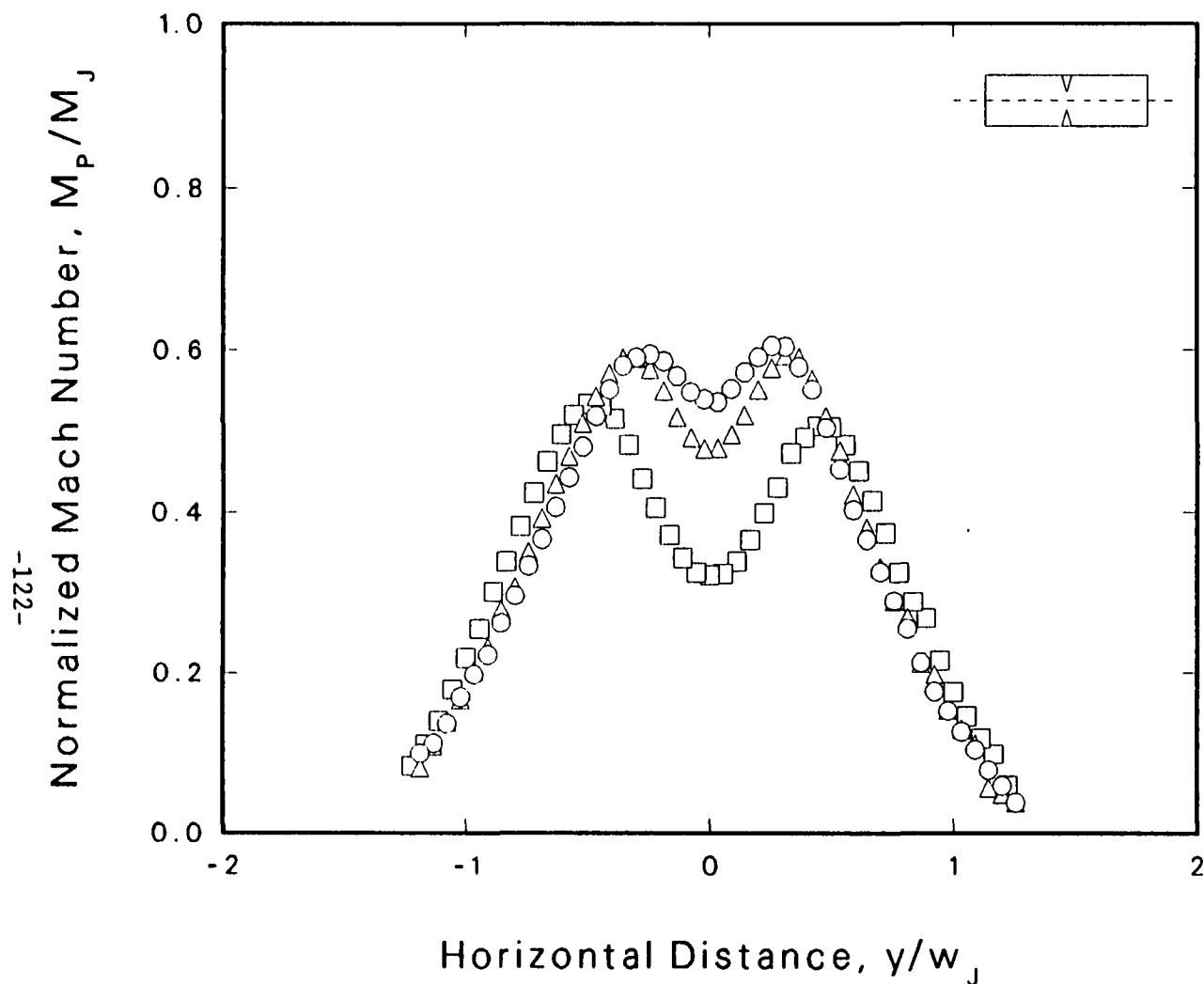
It was found that as the size of the tab was increased, the velocity profiles were further modified. This is shown in Figures 5.36 through 5.41 for the measurements at $M_j = 0.8$, $X/D_e = 9$, and for configurations I through VII for measurements made along the major axes. Similar measurements along the minor axes are presented in Figure 5.42 through 5.47.

Configurations that have tabs on the horizontal axis of the nozzle are especially sensitive to tab size as shown in Figure 5.48. The same thing happens for configuration VII-A which has four vertical tabs, all of which are off the jet axis as shown in Figure 5.49. When the tab size for configuration I was increased again to I-C, considerably more reduction in peak level was achieved.

In summary, large tabs are quite effective in reducing the peak jet velocity, of course with attendant increased thrust losses.

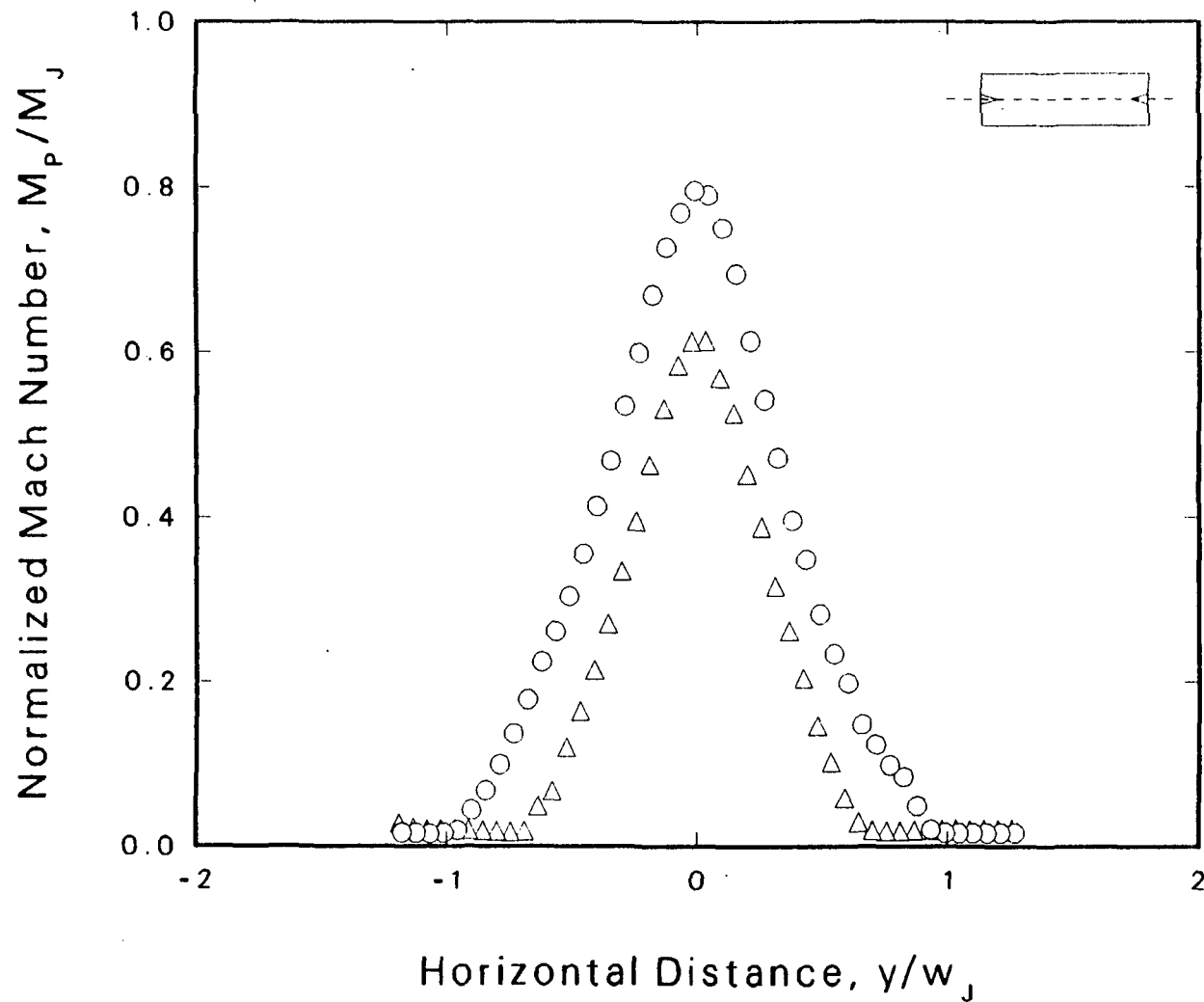
5.3.3 Tab Effects at Supersonic Mach Numbers

In Reference 1, the tabs were found to be particularly effective for supersonic circular jets. This was partly because of the introduction of streamwise trailing vortices in the flow that help engulf the ambient air, and partly due to the introduction of additional shocks at the tab that help slow down the flow. Similar results, although not so dramatic, were obtained for the rectangular supersonic jets. Typical velocity profiles for $M_j = 1.15$, measured at $X/D_e = 9$ for the minor axis are shown in Figures 5.50 through 5.53. Considerable reduction in the jet Mach numbers is obtained along the minor axis direction for all of the configurations tested. Effects along the major axis direction are not so dramatic as shown in Figures 5.54 through 5.60.



Sym	○	△	□
File	TAB157T	TAB149T	TAB365T
Config	I-A	I-B	I-C
M_j	0.799	0.799	0.797
T_{Tj}/T_A	1.01	0.97	1.00
T_{Tj} , K	284.0	286.0	282.2
U_j , mps	254.5	255.3	252.9
Re_{De}	1.095	1.083	1.105
Re_h	0.485	0.480	0.490
Re_w	1.938	1.917	1.956
p_A , kPa	98.442	98.239	98.950
T_A , K	281.9	294.6	281.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	-0.44
ΔY , mm	-3.0	-3.0	0.0

Figure 5.36 Effect of Tab Size on Configuration I
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Horiz. Velocity



Sym	○	△
File	TAB159T	TAB151T
Config	II-B	II-A
M_J	0.797	0.798
T_{TJ}/T_A	1.00	0.97
T_{TJ}, K	284.1	285.8
U_J, mps	253.7	254.8
Re_{De}	1.090	1.080
Re_h	0.483	0.479
Re_w	1.930	1.912
p_A, kPa	98.544	98.205
T_A, K	284.9	293.8
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	-4.0	-3.0

Figure 5.37 Effect of Tab Size on Configuration II
 $M_J=0.8$, $T_J/T_0=1$, $X/De=9$, Horiz. Profile

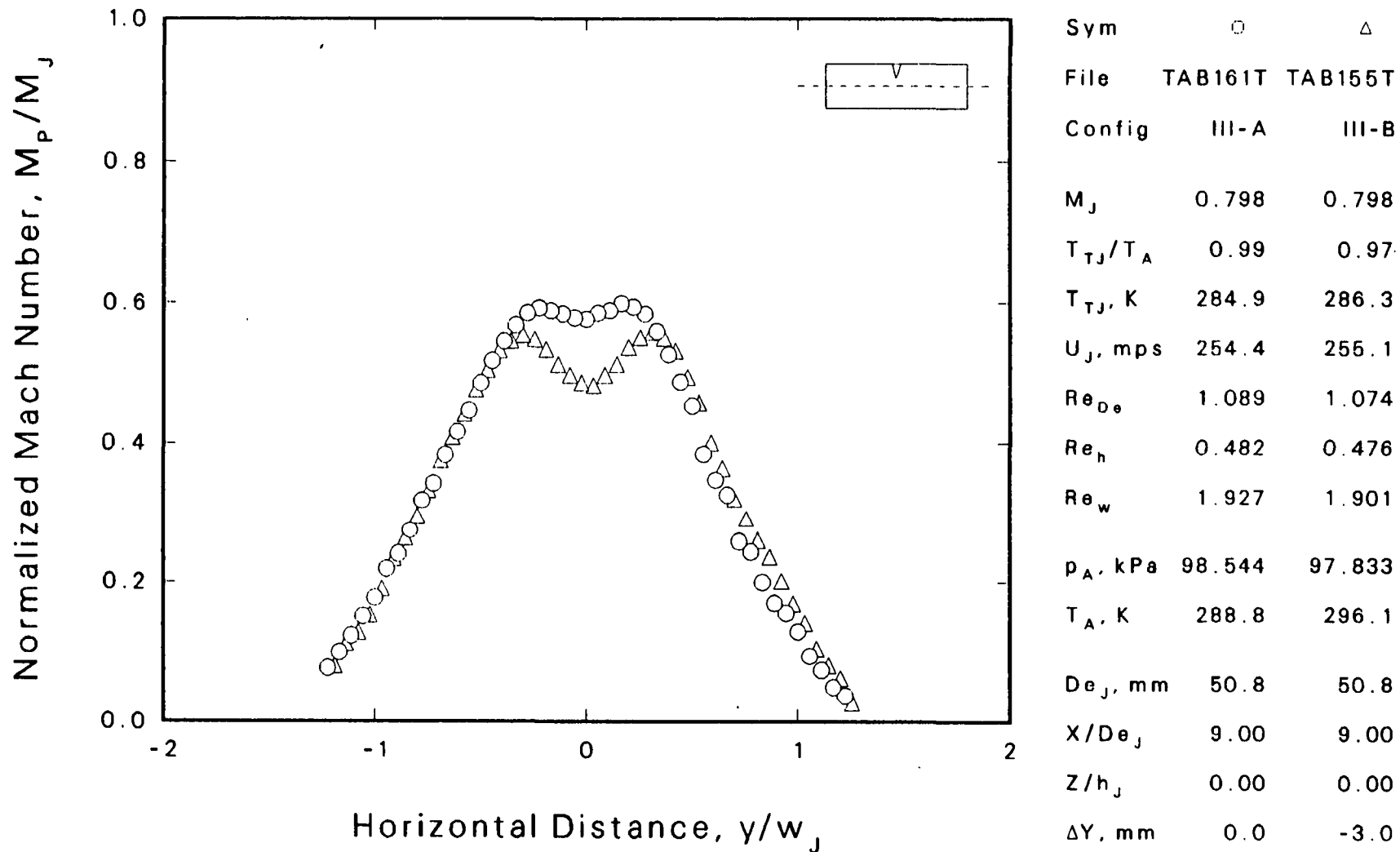
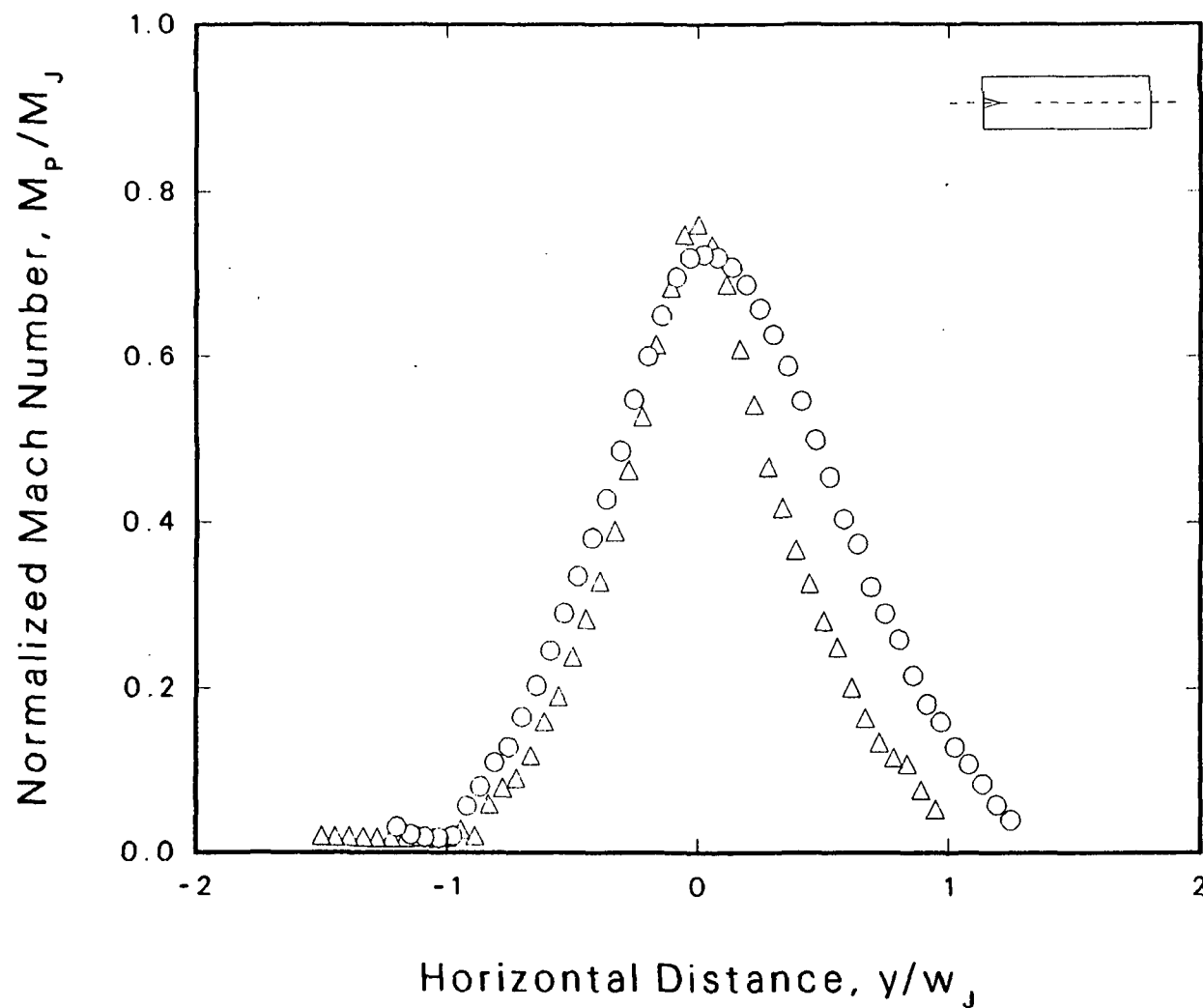
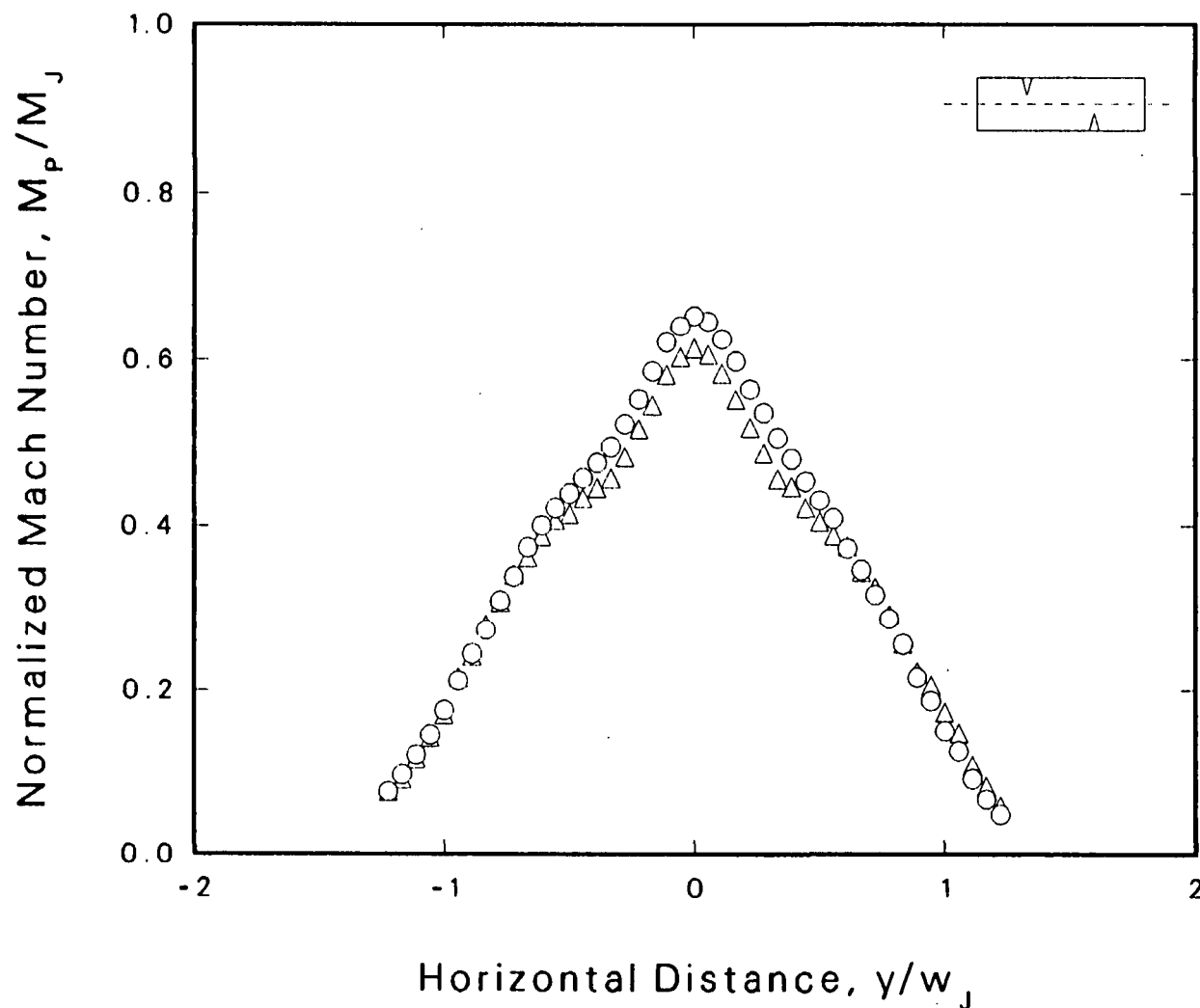


Figure 5.38 Effect of Tab Size on Configuration III
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Horiz. Profile



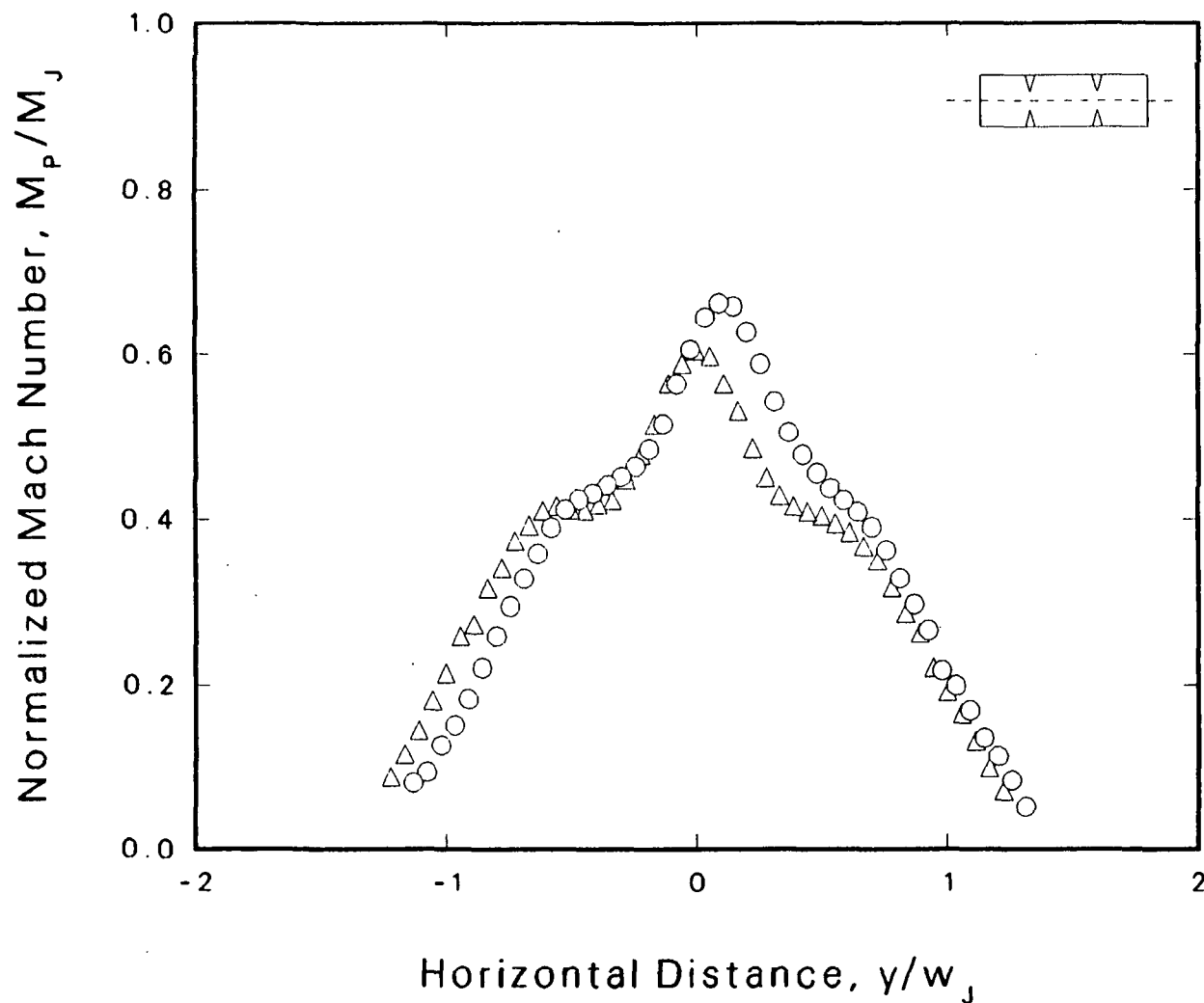
Sym	○	△
File	TAB163T	TAB153T
Config	IV-B	IV-A
M_j	0.796	0.797
T_{Tj}/T_A	0.99	0.97
T_{Tj}, K	285.0	286.4
U_j, mps	254.0	254.9
Re_{De}	1.085	1.075
Re_h	0.480	0.476
Re_w	1.920	1.902
p_A, kPa	98.476	98.070
T_A, K	289.1	294.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-2.0	25.0

Figure 5.39 Effect of Tab Size on Configuration IV
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Horiz. Profile



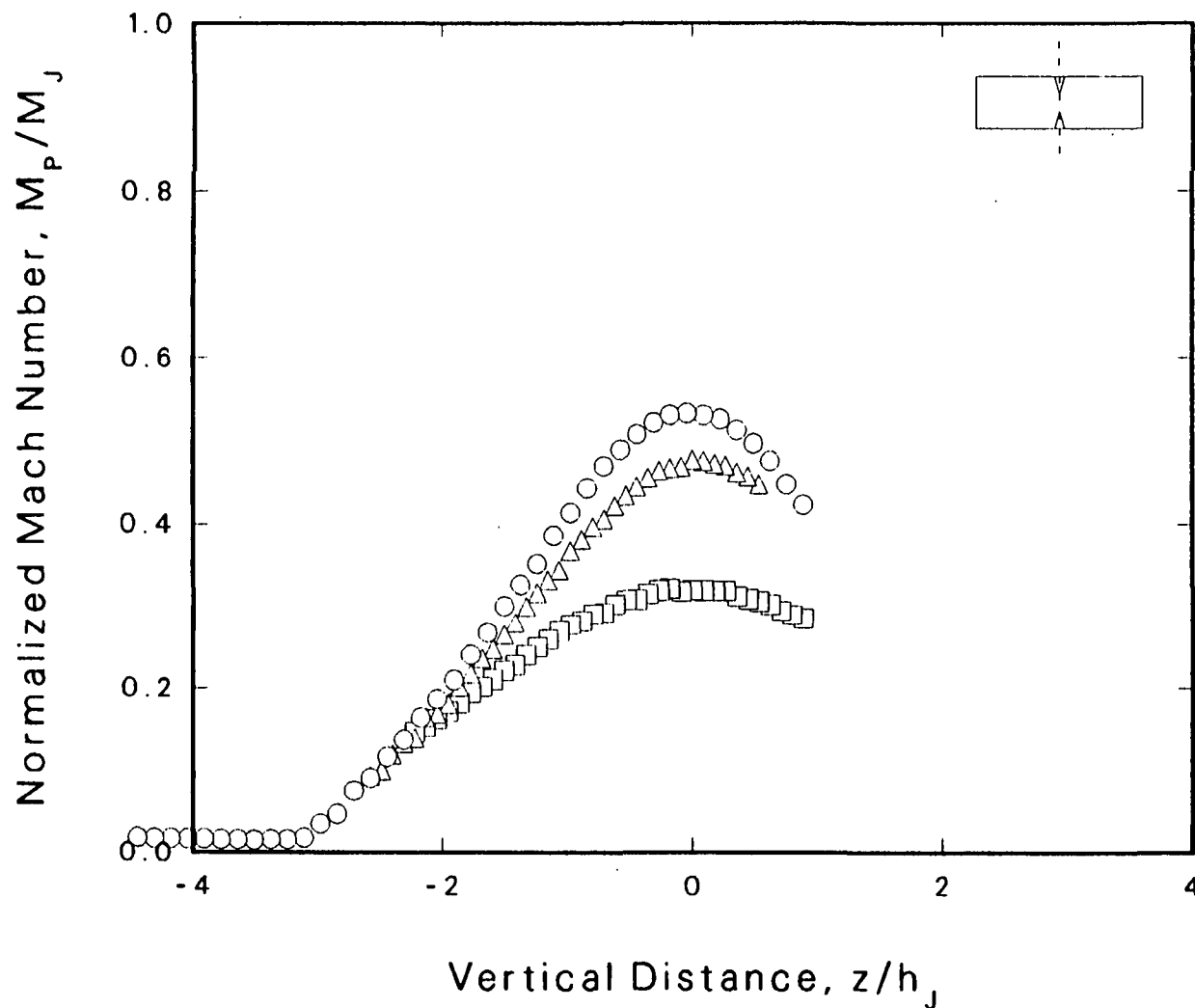
Sym	○	△
File	TAB242T	TAB252T
Config	VI-A	VI-B
M_j	0.798	0.796
T_{Tj}/T_A	0.99	1.01
T_{Tj}, K	280.6	279.0
U_j, mps	252.5	251.2
Re_{De}	1.100	1.114
Re_h	0.487	0.493
Re_w	1.947	1.972
p_A, kPa	97.562	98.408
T_A, K	282.1	277.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 5.40 Effect of Tab Size on Configuration VI
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Horiz. Profile



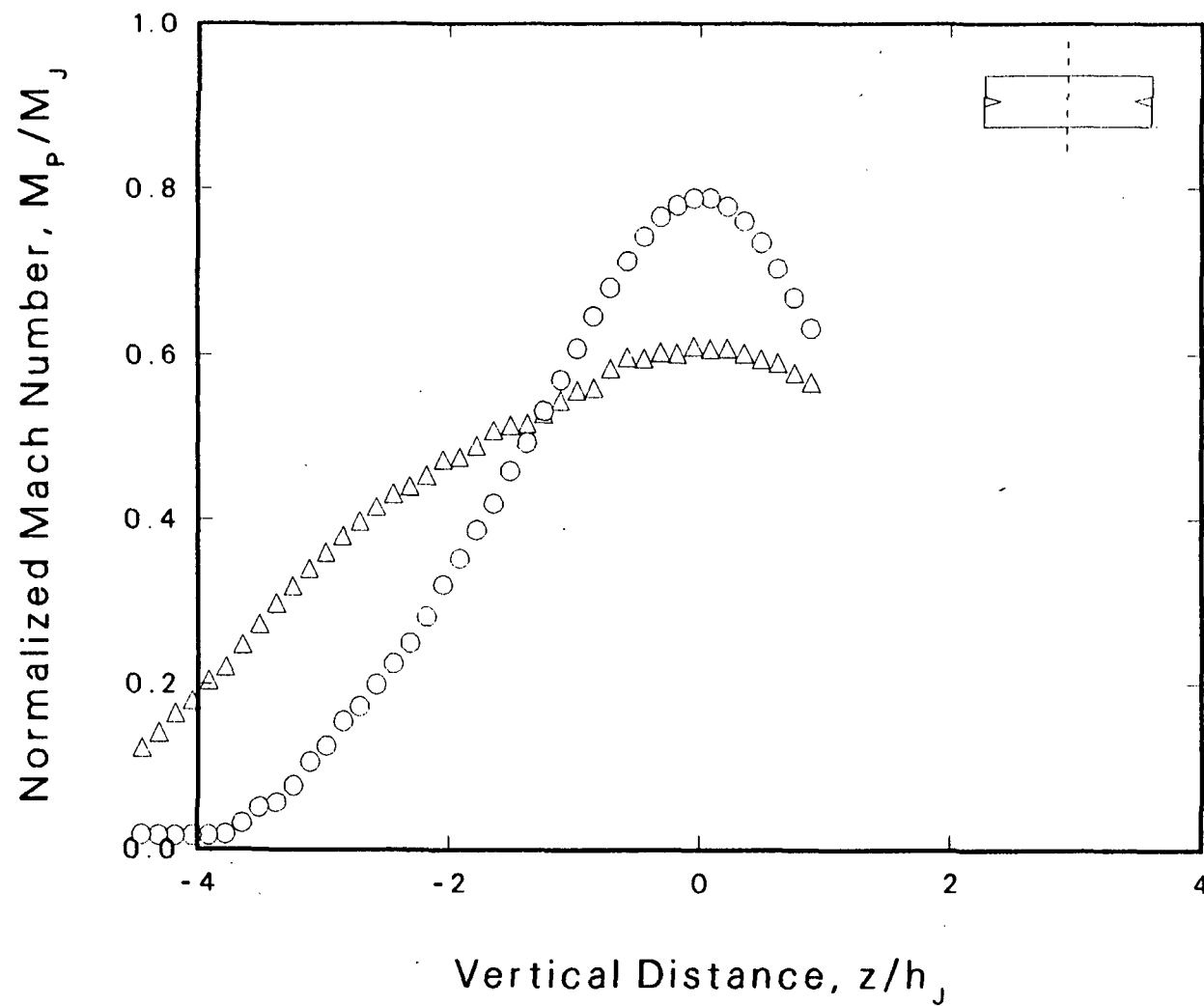
Sym	○	△
File	TAB239T	TAB248T
Config	VII-A	VII-B
M_j	0.796	0.799
T_{Tj}/T_A	0.98	0.98
T_{Tj} , K	281.0	280.9
U_j , mps	252.2	252.8
Re_{De}	1.101	1.094
Re_h	0.488	0.485
Re_w	1.950	1.937
p_A , kPa	98.171	97.156
T_A , K	286.8	286.7
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	-8.0	0.0

Figure 5.41 Effect of Tab Size on Configuration VII
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Horiz. Profile



Sym	O	Δ	□
File	TAB158T	TAB148T	TAB364T
Config	I-A	I-B	I-C
M_j	0.797	0.797	0.797
T_{TJ}/T_A	1.00	0.97	1.01
T_{TJ}, K	284.1	286.3	281.8
U_j, mps	253.9	264.8	252.8
Re_{De}	1.091	1.078	1.108
Re_h	0.483	0.478	0.491
Re_w	1.932	1.909	1.960
p_A, kPa	98.510	98.341	98.916
T_A, K	282.9	294.8	280.1
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	0.0	-2.0	-10.0

Figure 5.42 Effect of Tab Size on Configuration I
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Vertical Profile



Sym	O	Δ
File	TAB160T	TAB152T
Config	II-B	II-A
M_j	0.796	0.797
T_{Tj}/T_A	0.99	0.98
T_{Tj}, K	284.3	285.3
U_j, mps	253.6	254.5
Re_{De}	1.089	1.082
Re_h	0.482	0.479
Re_w	1.928	1.915
p_A, kPa	98.612	98.171
T_A, K	286.0	289.7
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	0.0	0.0

Figure 5.43 Effect of Tab Size on Configuration II
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Vertical Profile

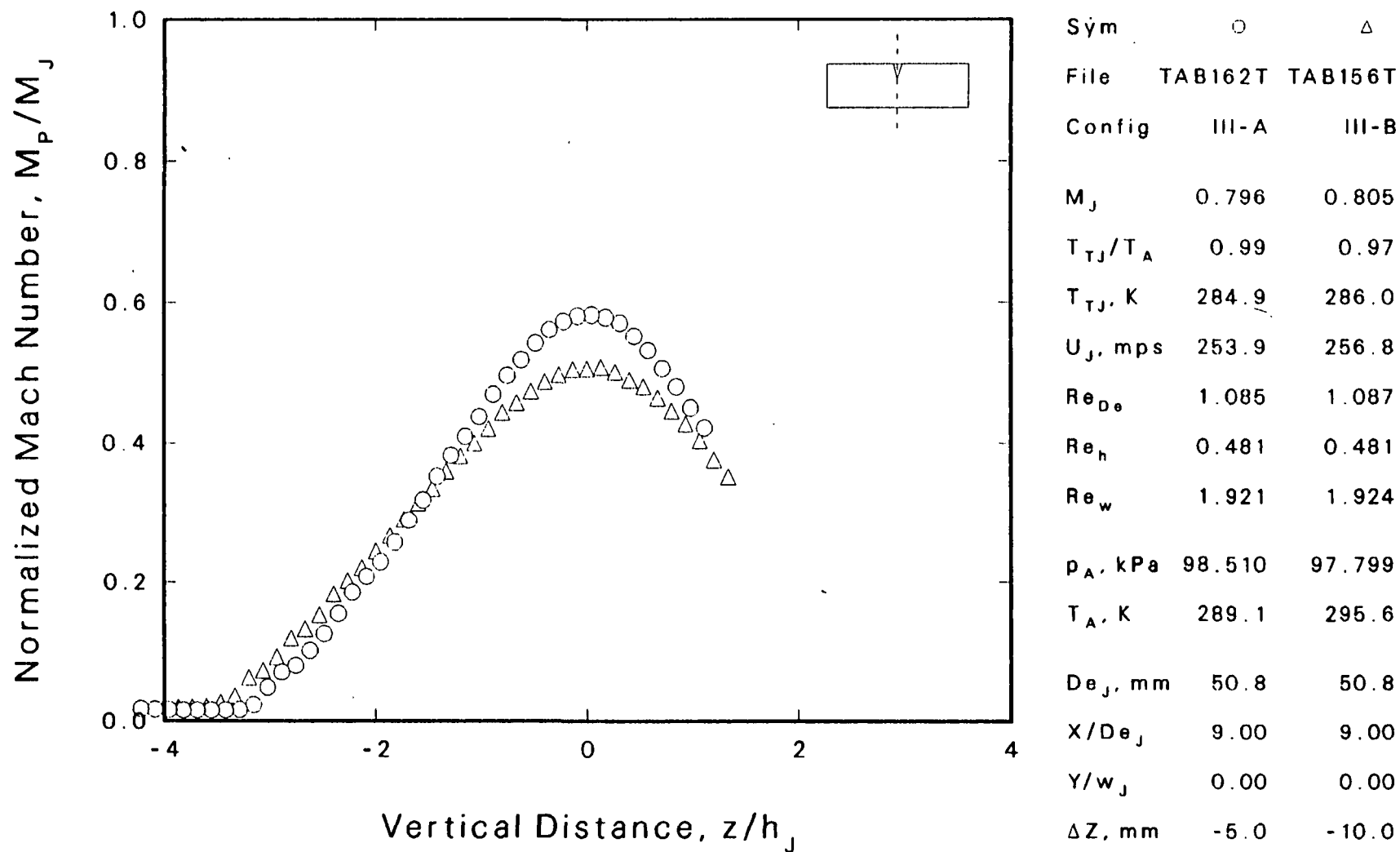
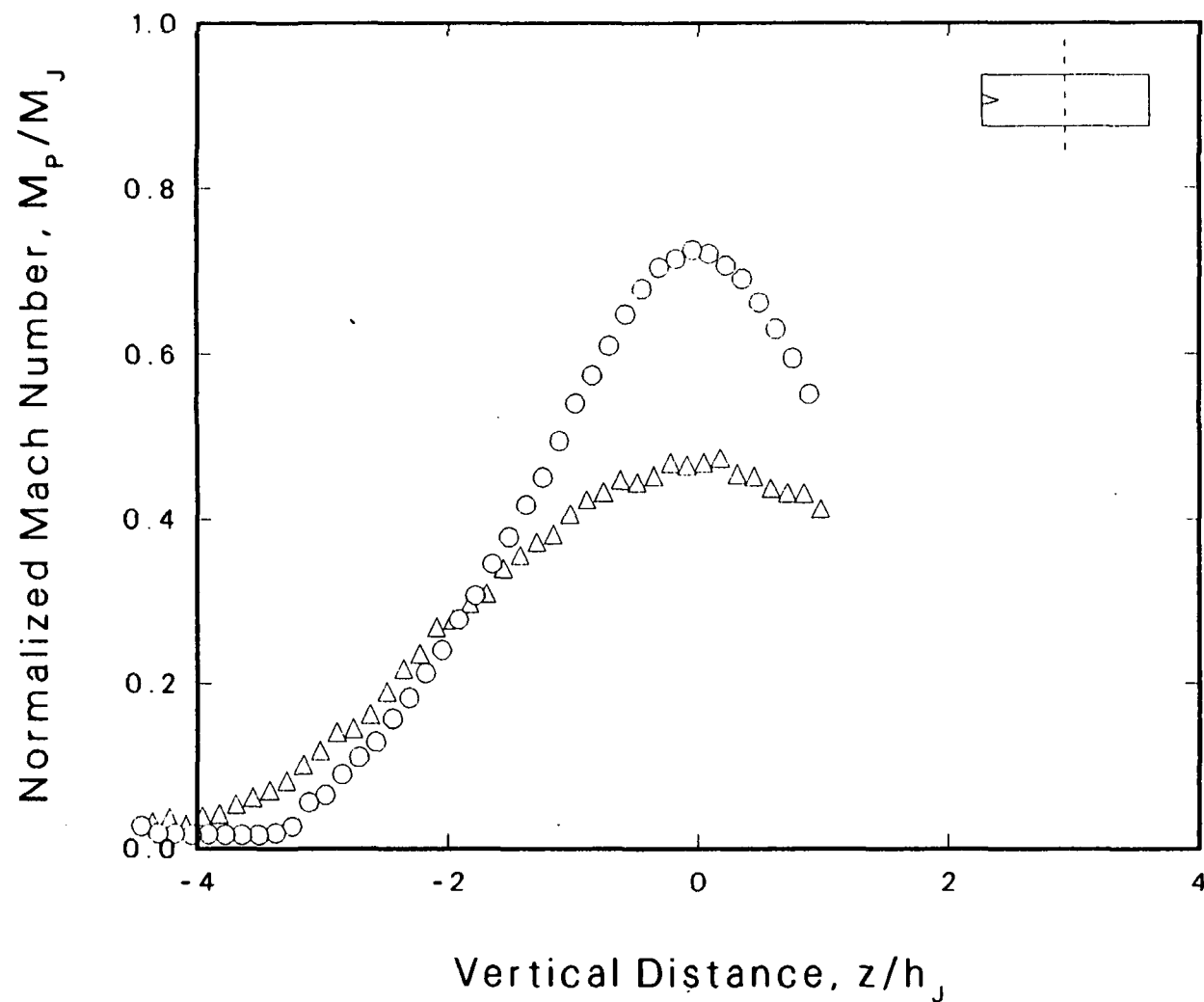


Figure 5.44 Effect of Tab Size on Configuration III
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Vertical Profile



Sym	O	Δ
File	TAB164T	TAB154T
Config	IV-B	IV-A
M_j	0.802	0.802
T_{TJ}/T_A	0.99	0.97
T_{TJ}, K	284.7	286.8
U_j, mps	255.4	256.3
Re_{De}	1.095	1.079
Re_h	0.485	0.478
Re_w	1.939	1.910
p_A, kPa	98.476	97.901
T_A, K	288.3	296.5
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	0.0	-2.0

Figure 5.45 Effect of Tab Size on Configuration IV
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Vertical Profile

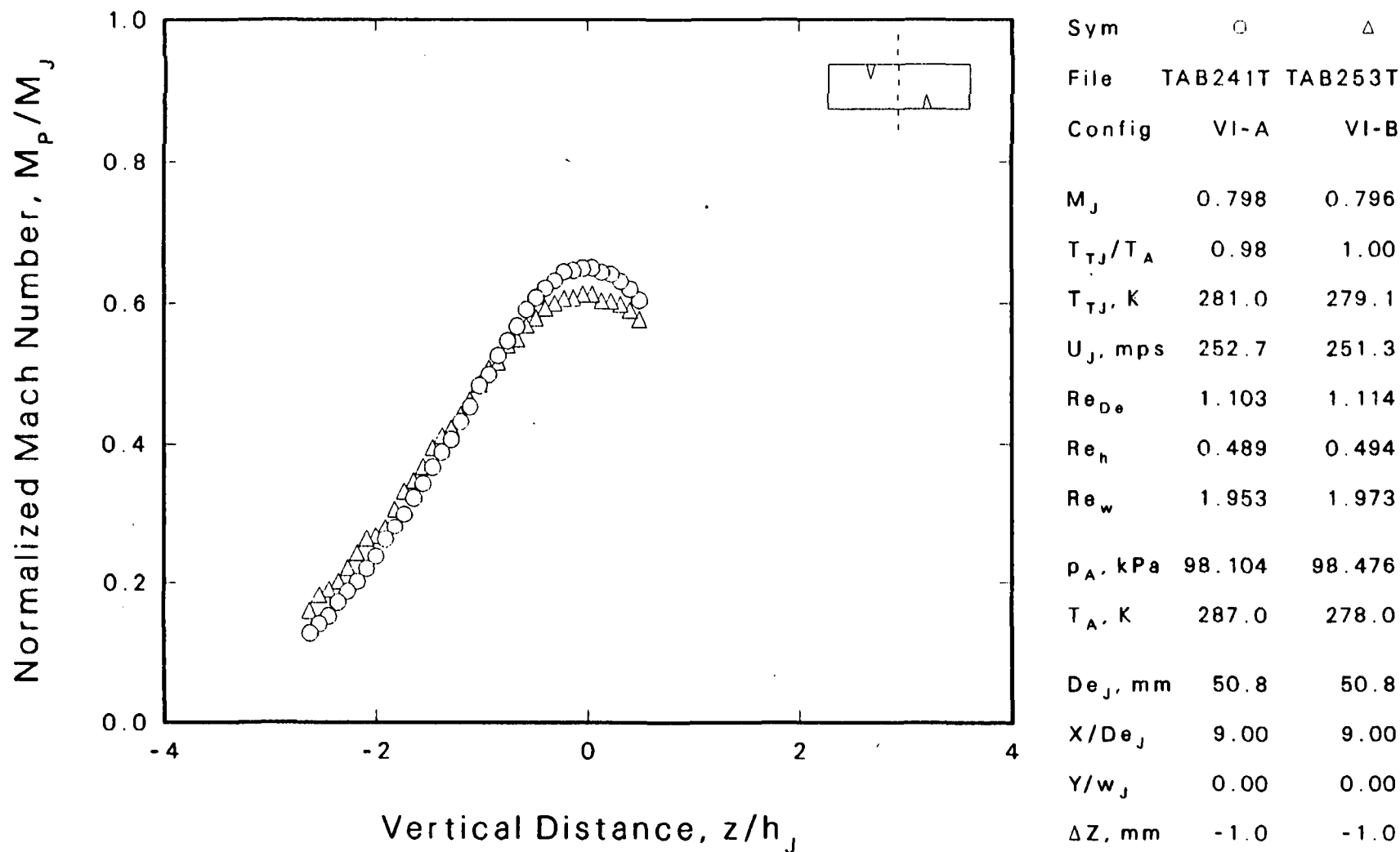


Figure 5.46 Effect of Tab Size on Configuration VI
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Vertical Profile

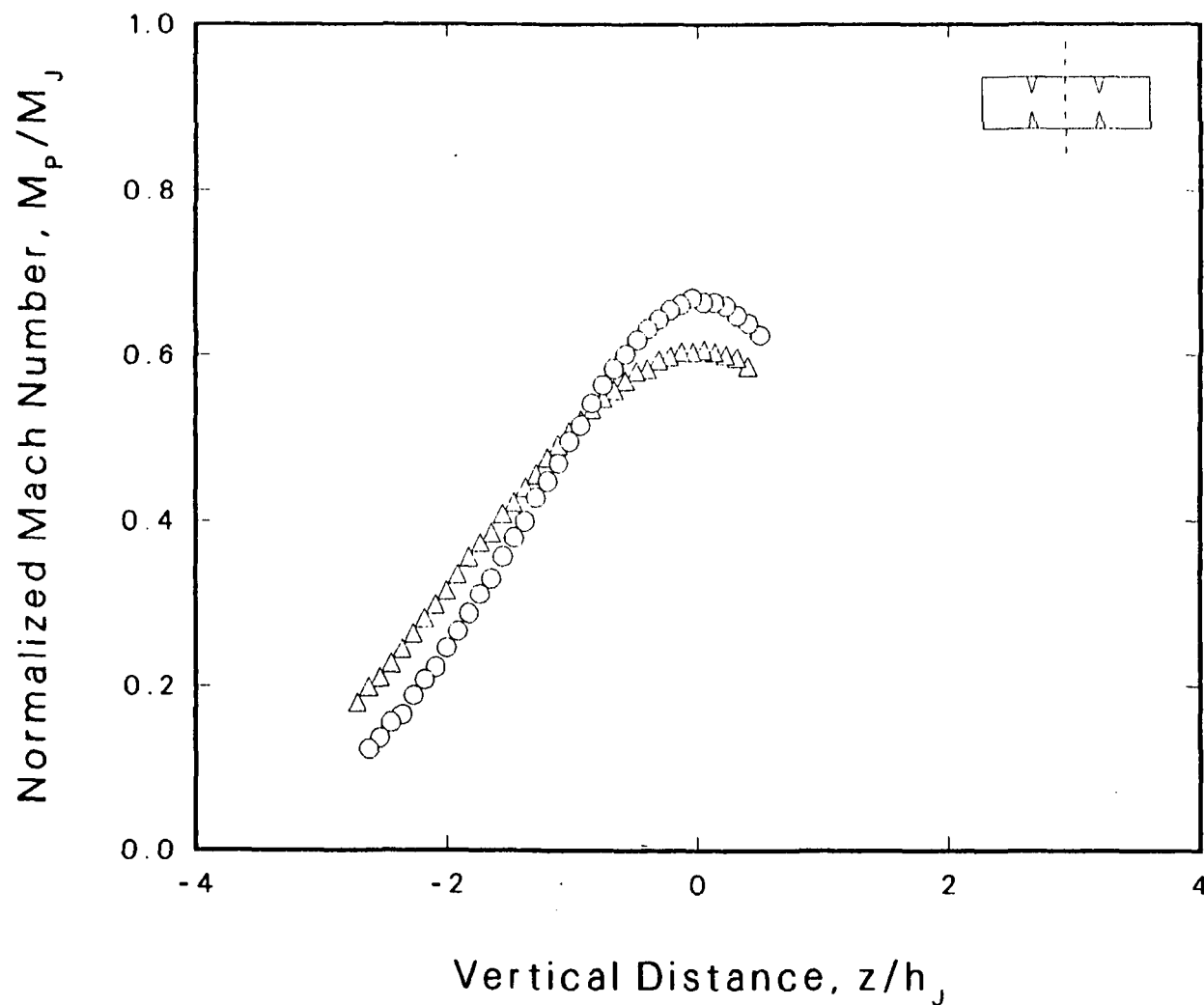
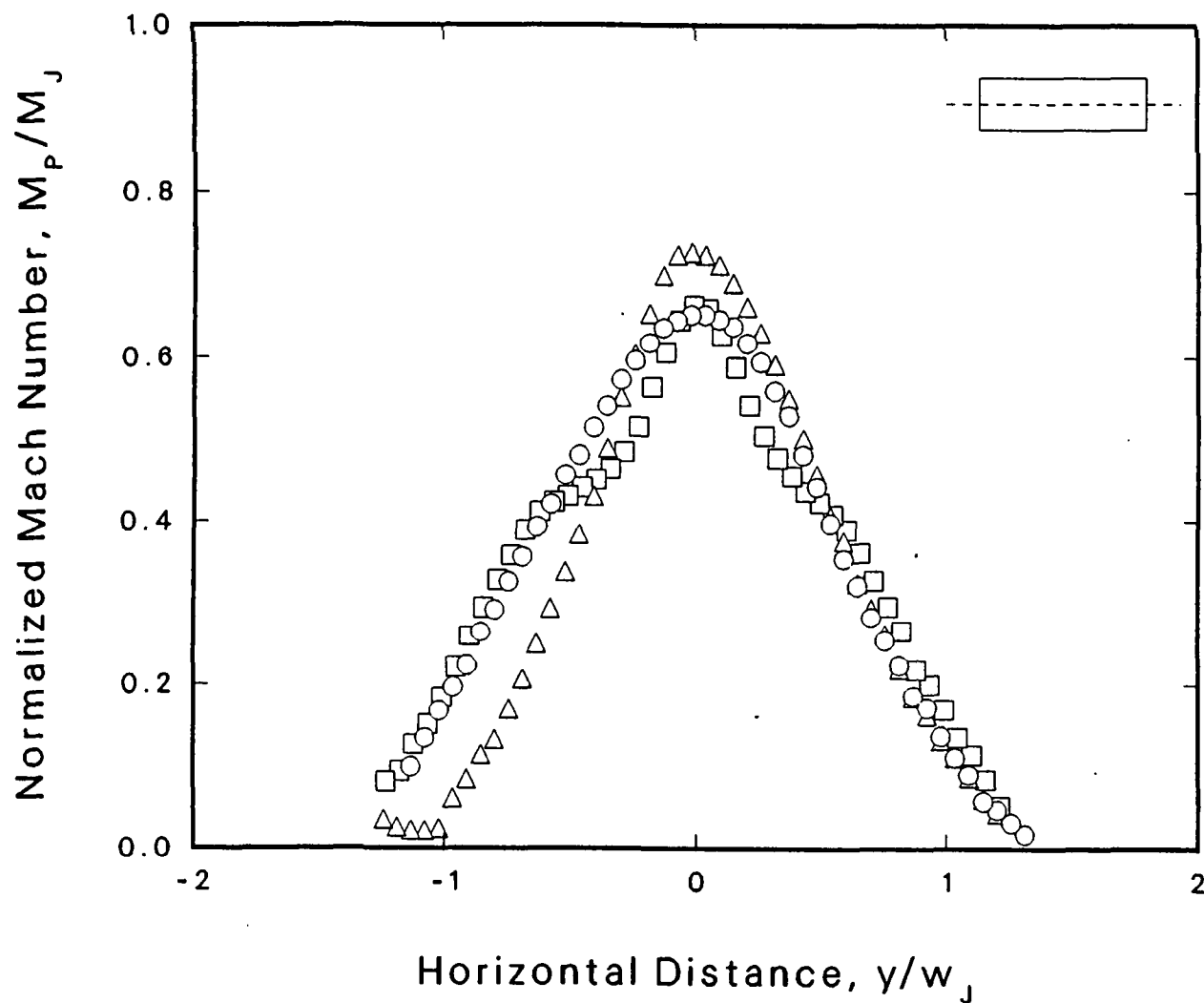
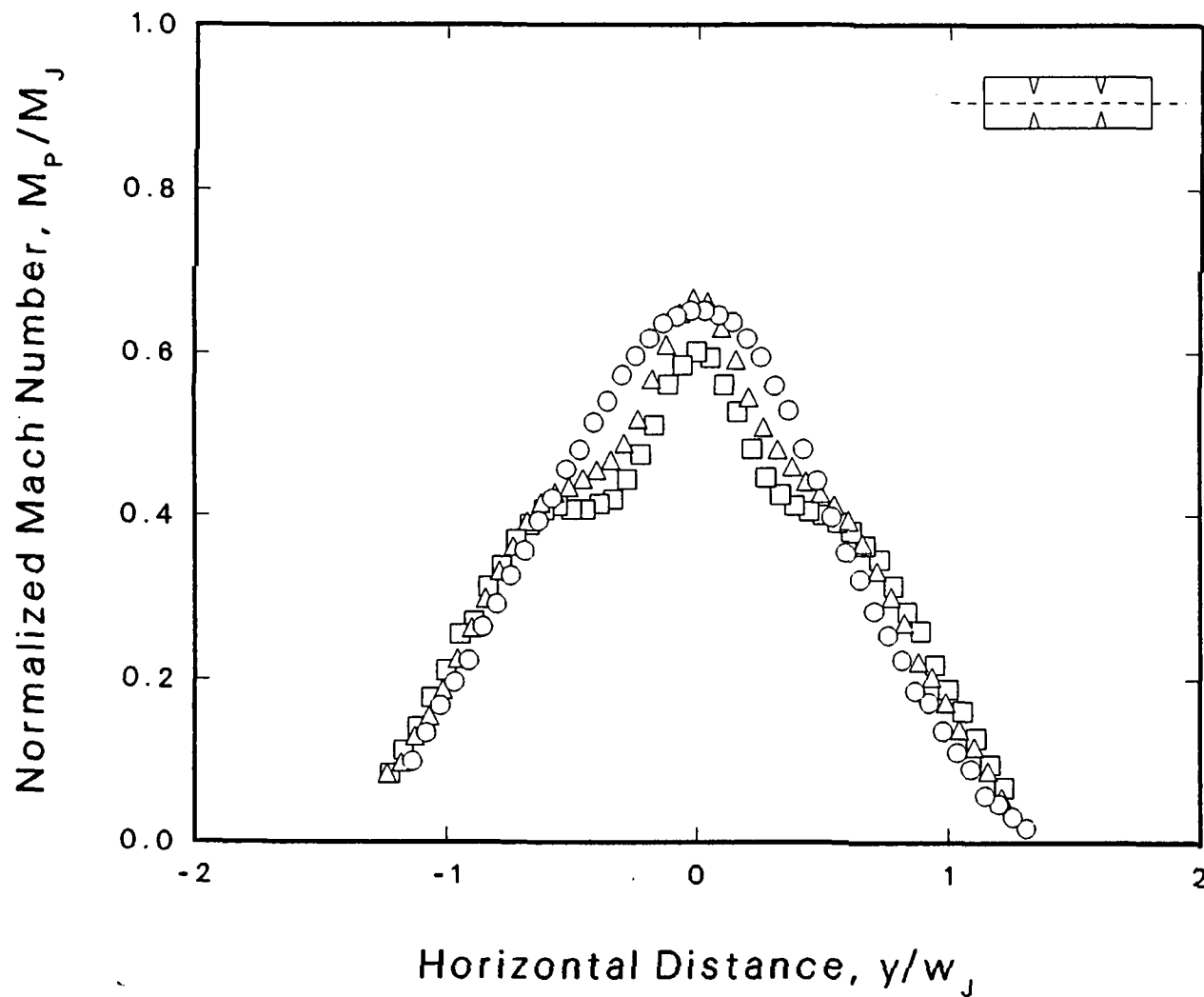


Figure 5.47 Effect of Tab Size on Configuration VII
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$, Vertical Profile



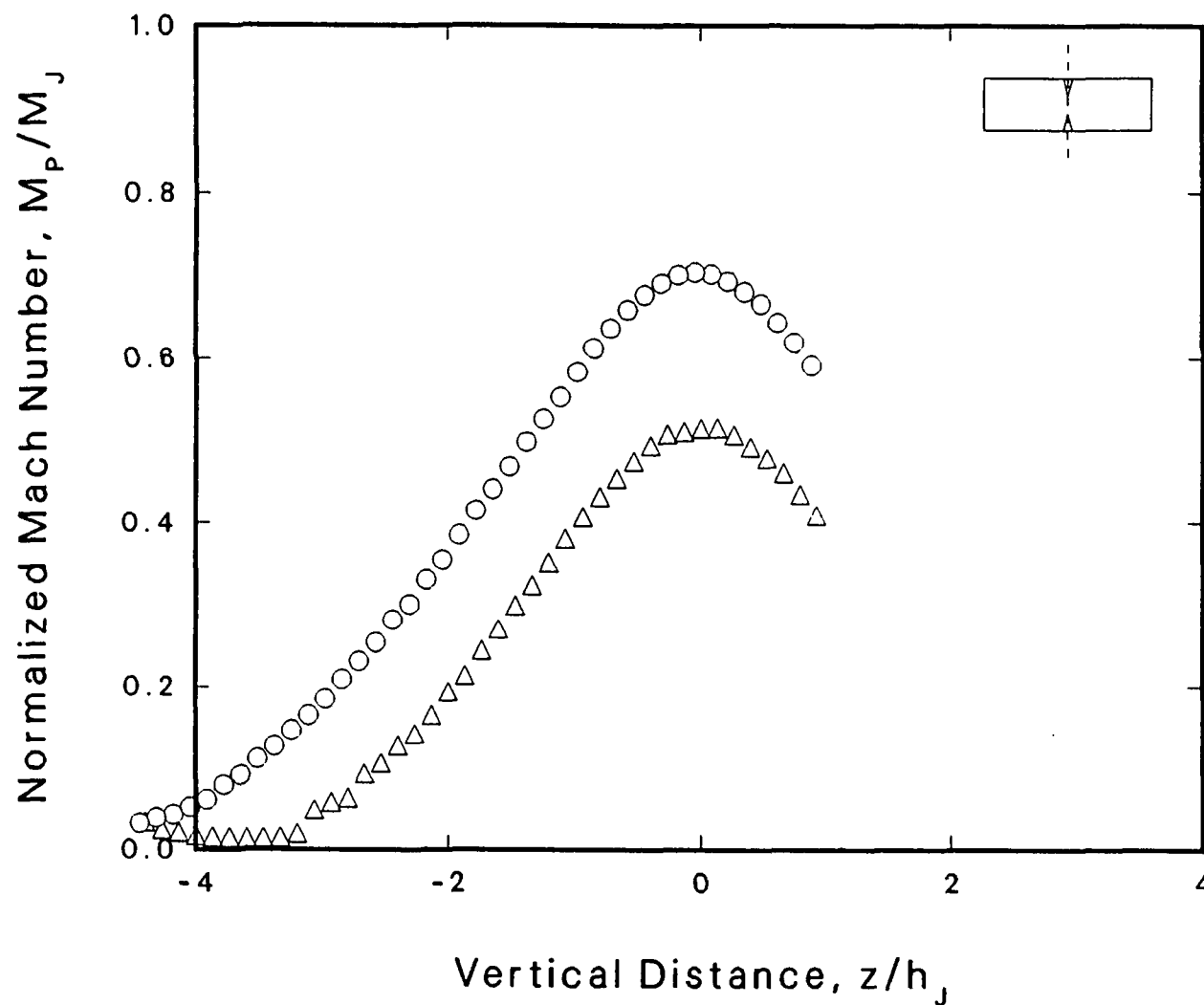
Sym	○	△	□
File	TAB147T	TAB163T	TAB239T
Config	0-0	IV-B	VII-A
M_j	0.800	0.796	0.796
T_{Tj}/T_A	0.97	0.99	0.98
T_{Tj}, K	285.5	285.0	281.0
U_j, mps	255.2	254.0	252.2
Re_{De}	1.087	1.085	1.101
Re_h	0.482	0.480	0.488
Re_w	1.925	1.920	1.950
p_A, kPa	98.375	98.476	98.171
T_A, K	294.6	289.1	286.8
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	-8.0	2.0	1.0

Figure 5.48 Configurations with Bulging Profiles
 $M_j=0.8$, $T_j/T_0=1$, $X/De=9$



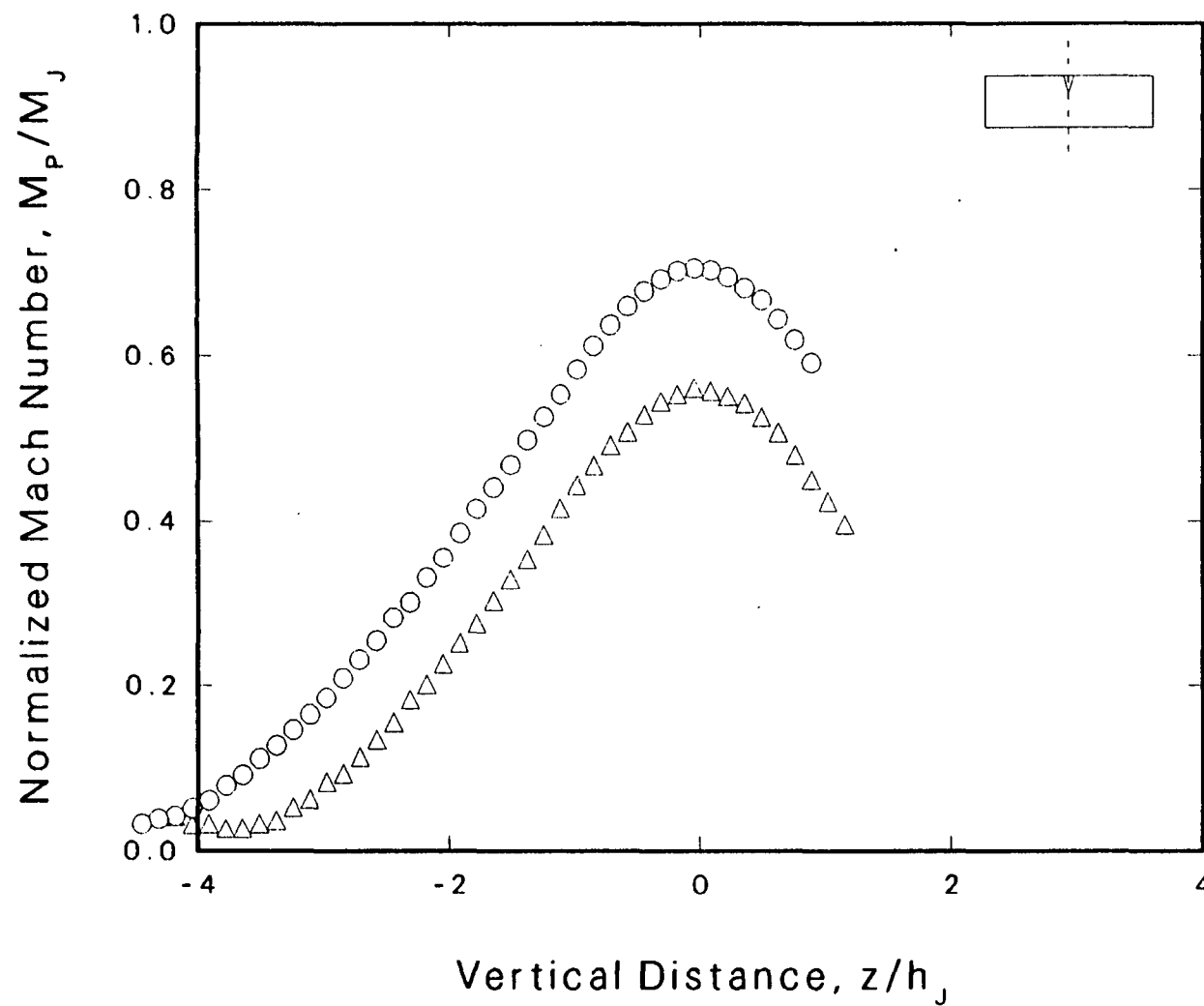
Sym	○	△	□
File	TAB147T	TAB239T	TAB248T
Config	0-0	VII-A	VII-B
M_j	0.800	0.796	0.799
T_{TJ}/T_A	0.97	0.98	0.98
T_{TJ} , K	285.5	281.0	280.9
U_j , mps	255.2	252.2	252.8
Re_{De}	1.087	1.101	1.094
Re_h	0.482	0.488	0.485
Re_w	1.925	1.950	1.937
p_A , kPa	98.375	98.171	97.156
T_A , K	294.6	286.8	286.7
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	-8.0	1.0	0.0

Figure 5.49 Configuration VII vs Baseline, Horizontal
 $M_j=0.8$



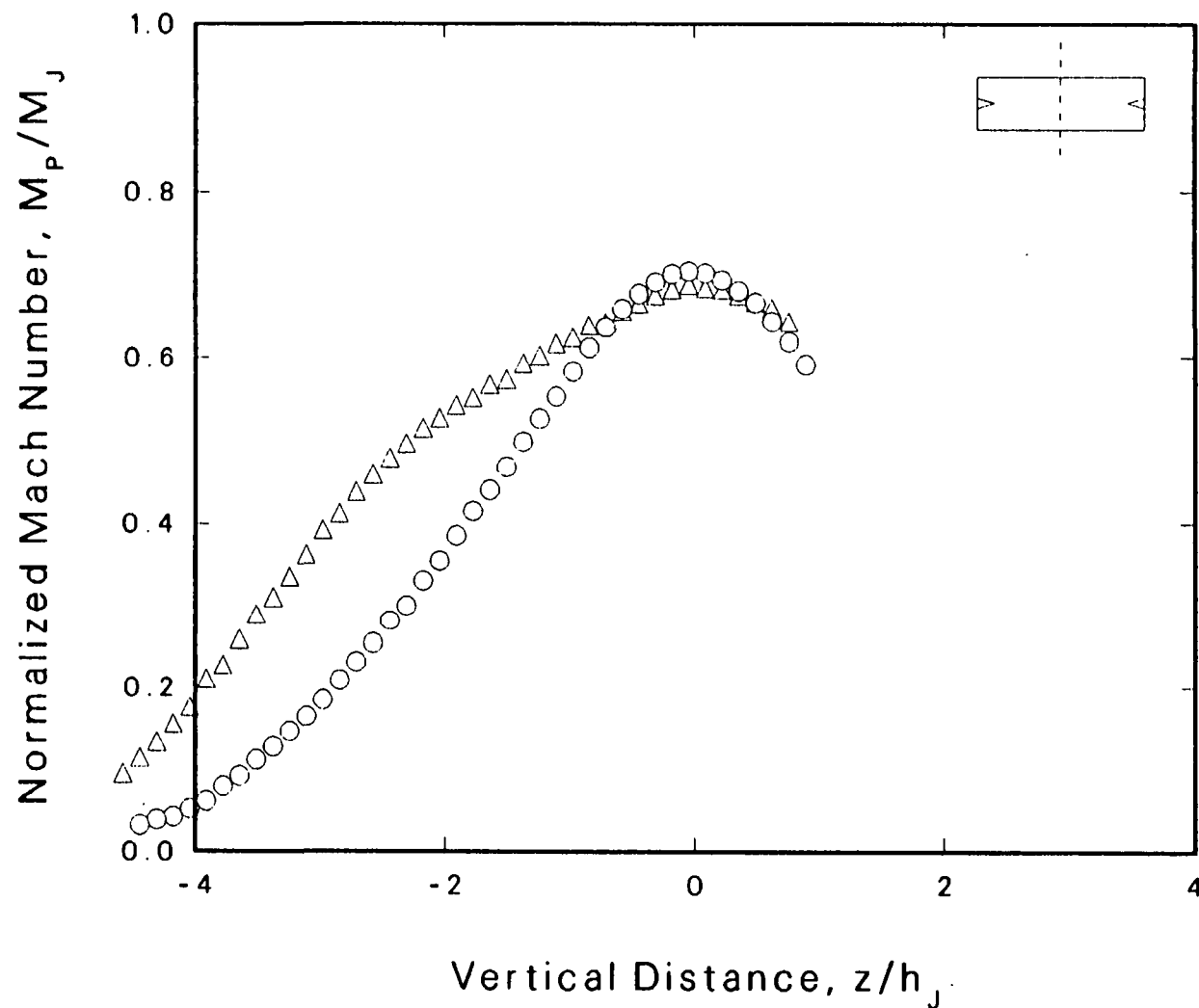
Sym	O	Δ
File	TAB203T	TAB195T
Config	0-0	I-B
M_j	1.151	1.149
T_{TJ}/T_A	0.99	1.00
T_{TJ}, K	283.1	283.5
U_j, mps	345.3	345.0
Re_{De}	1.842	1.831
Re_h	0.816	0.811
Re_w	3.260	3.241
p_A, kPa	98.375	98.273
T_A, K	284.7	283.6
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	0.0	-1.0

Figure 5.50 Vertical Profile for Configuration I-B
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



Sym	○	△
File	TAB203T	TAB197T
Config	0-0	III-B
M_j	1.151	1.148
T_{Tj}/T_A	0.99	1.03
T_{Tj} , K	283.1	282.0
U_j , mps	345.3	344.0
Re_{De}	1.842	1.848
Re_h	0.816	0.819
Re_w	3.260	3.271
p_A , kPa	98.375	98.578
T_A , K	284.7	273.9
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	0.0	-6.0

Figure 5.51 Vertical Profile for Configuration III-B
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



Sym	O	Δ
File	TAB203T	TAB206T
Config	0-0	II-A
M_j	1.151	1.148
T_{Tj}/T_A	0.99	1.00
T_{Tj} , K	283.1	282.9
U_j , mps	345.3	344.5
Re_{De}	1.842	1.837
Re_h	0.816	0.814
Re_w	3.260	3.252
p_A , kPa	98.375	98.408
T_A , K	284.7	283.6
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	0.0	3.0

Figure 5.52 Vertical Profile for Configuration II-A
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$

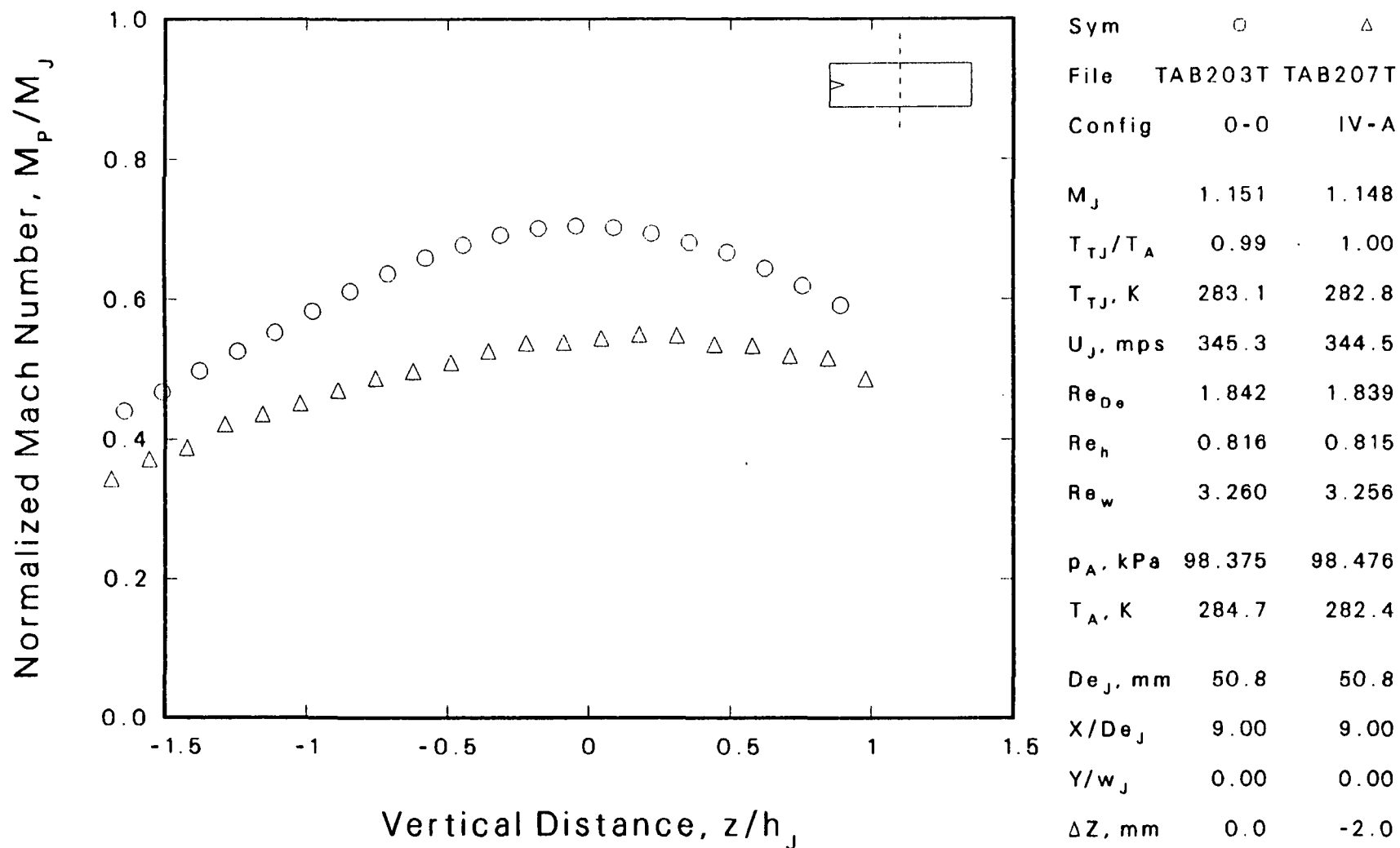
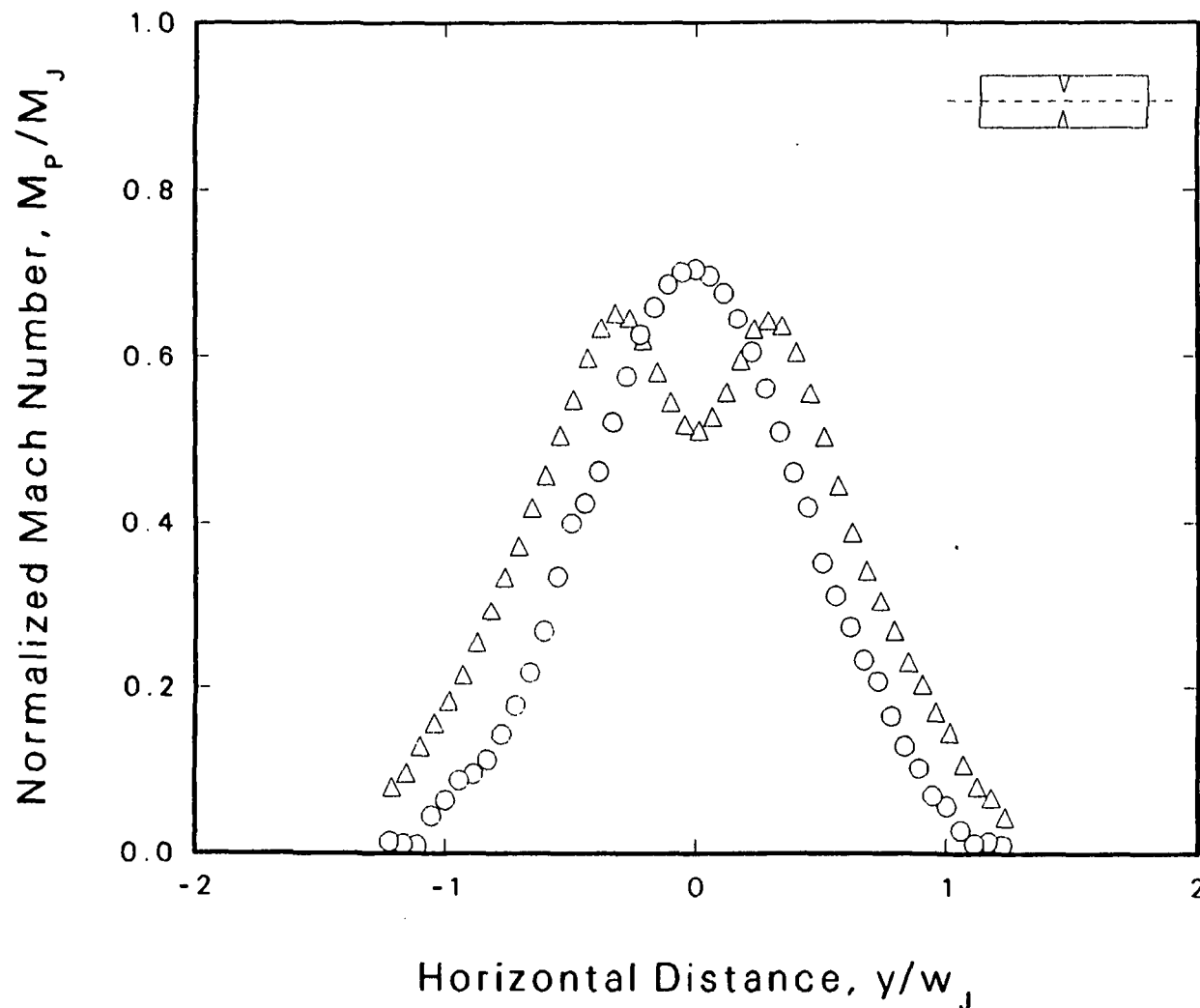
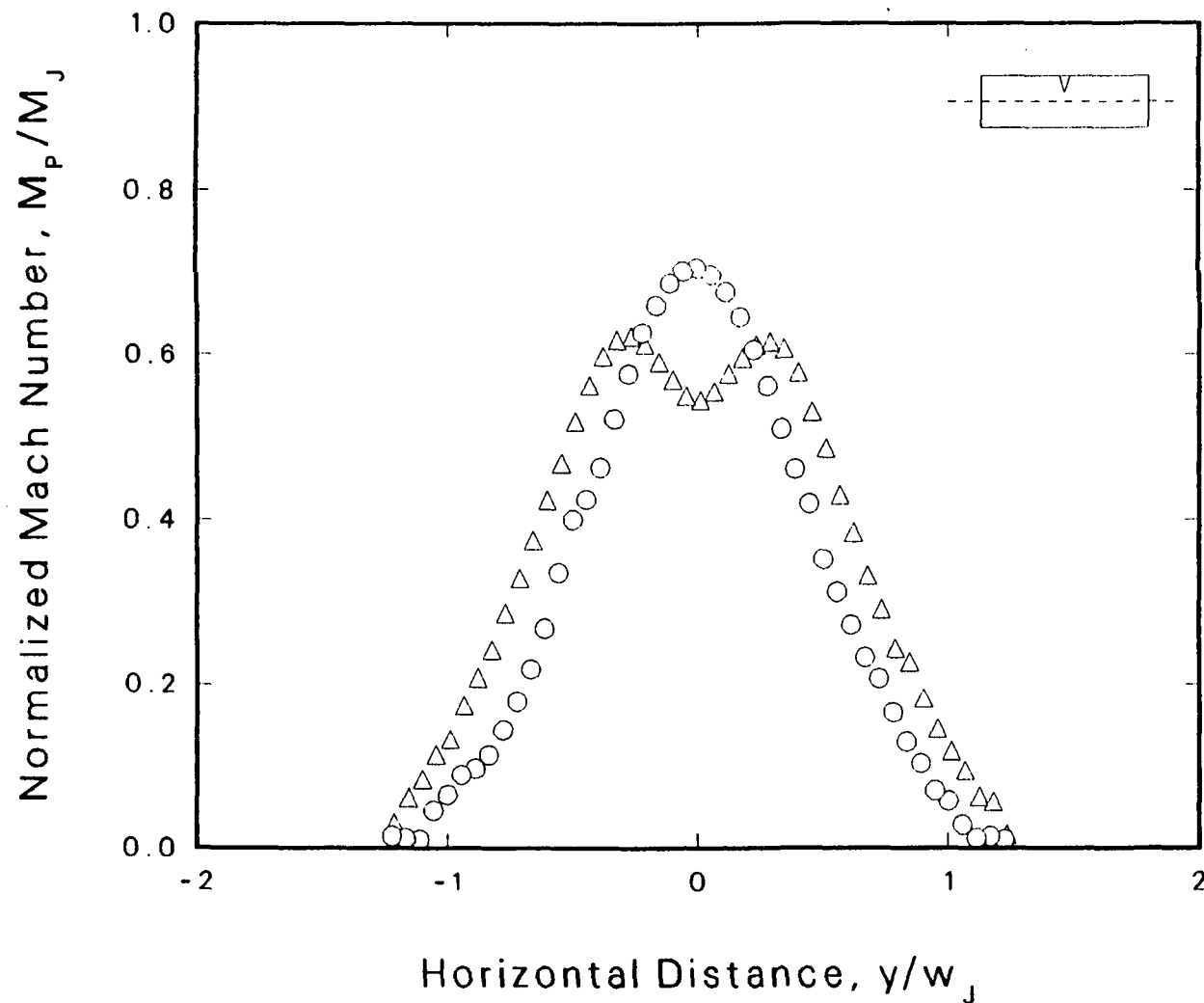


Figure 5.53 Vertical Profile for Configuration IV-A
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



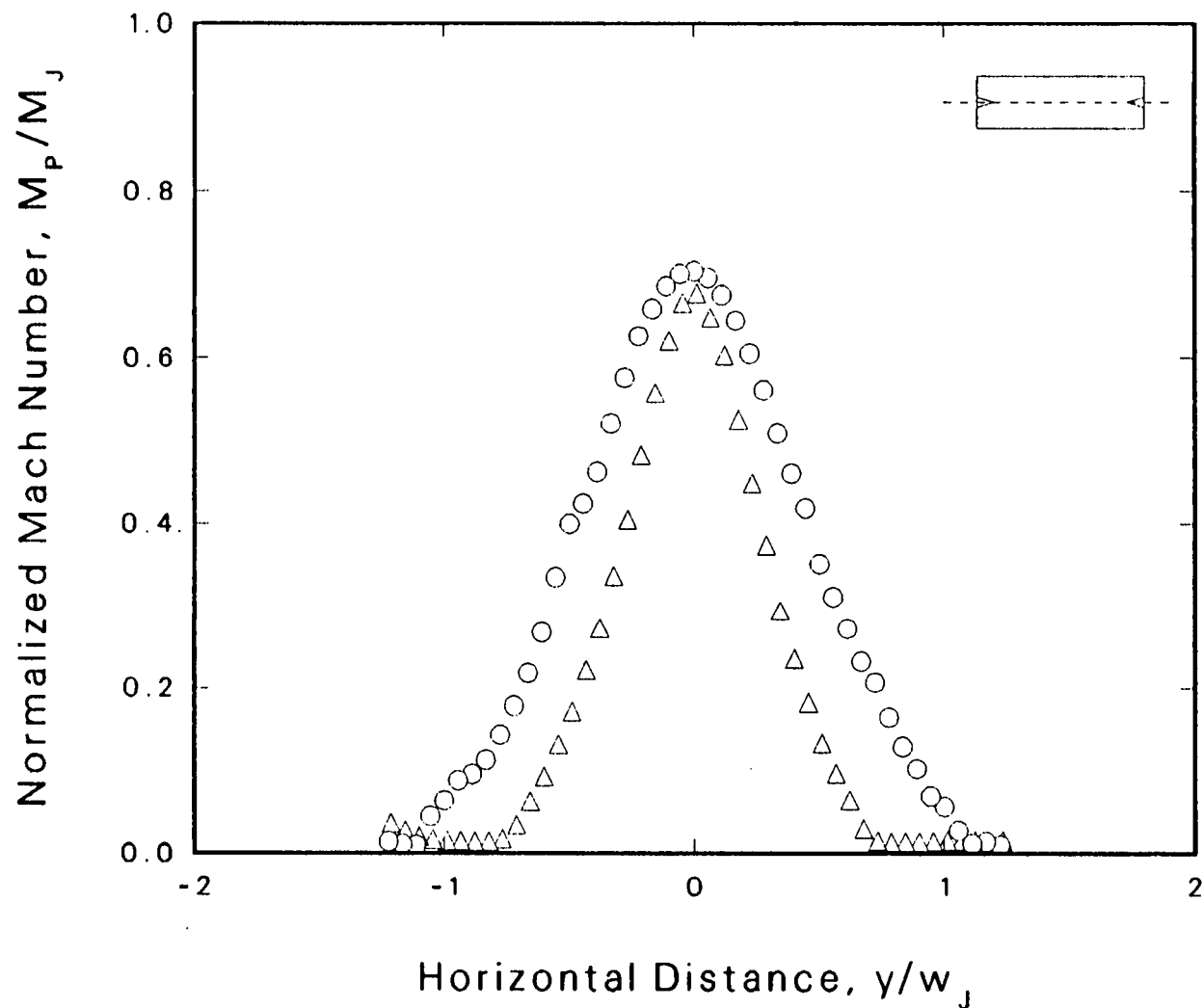
Sym	□	Δ
File	TAB185T	TAB196T
Config	0-0	I-B
M_J	1.148	1.148
T_{TJ}/T_A	1.01	1.00
T_{TJ}, K	283.3	283.7
U_J, mps	344.7	345.0
Re_{De}	1.831	1.827
Re_h	0.811	0.809
Re_w	3.241	3.233
p_A, kPa	98.273	98.205
T_A, K	280.4	284.7
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.54 Horizontal Profile for Configuration I-B
 $M_J=1.15$, $T_J/T_0=1$, $X/De=9$



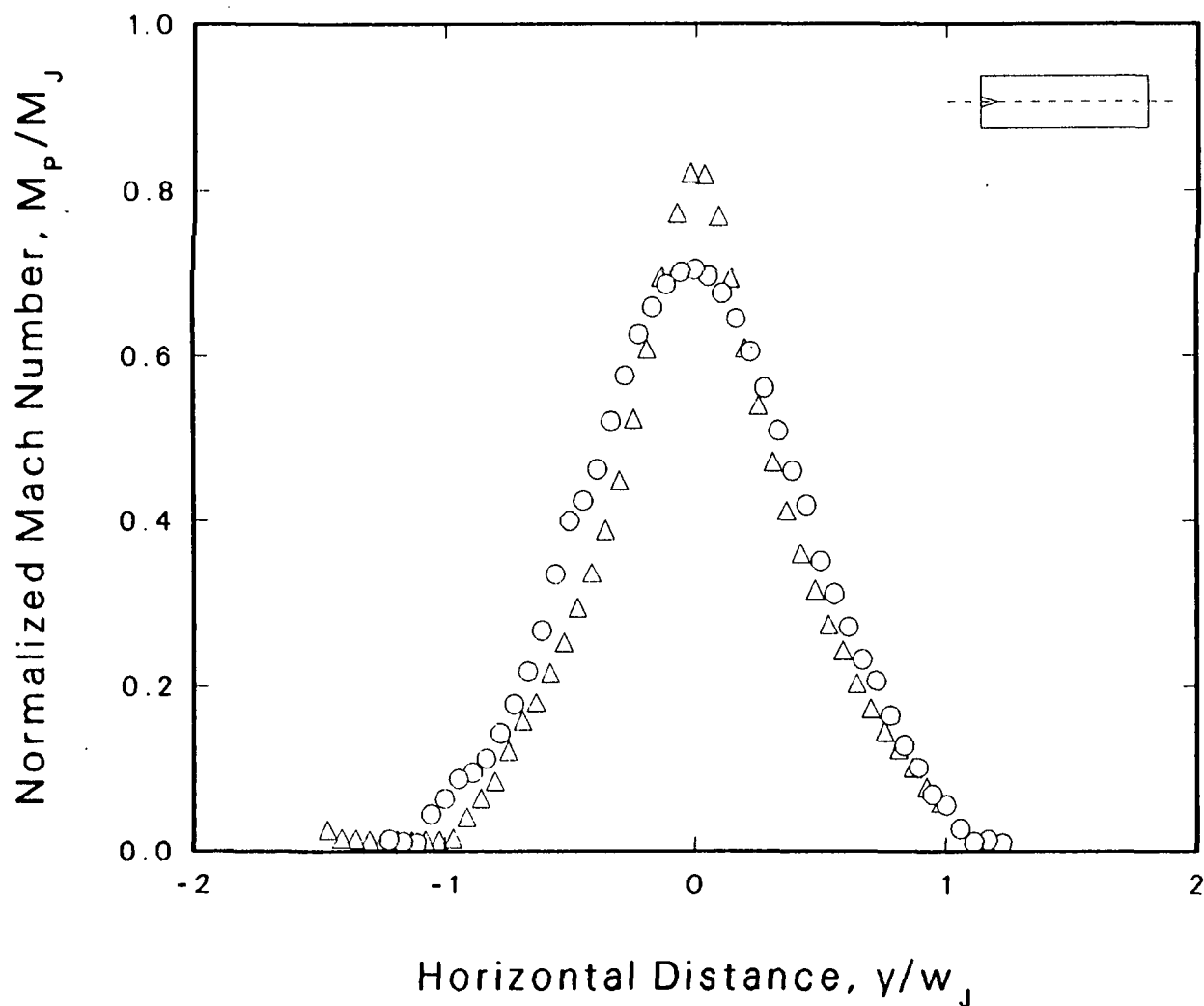
Sym	O	Δ
File	TAB185T	TAB198T
Config	0-0	III-B
M_j	1.148	1.147
T_{Tj}/T_A	1.01	1.02
T_{Tj}, K	283.3	282.3
U_j, mps	344.7	343.8
Re_{De}	1.831	1.843
Re_h	0.811	0.816
Re_w	3.241	3.261
p_A, kPa	98.273	98.612
T_A, K	280.4	277.2
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.55 Horizontal Profile for Configuration III-B
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



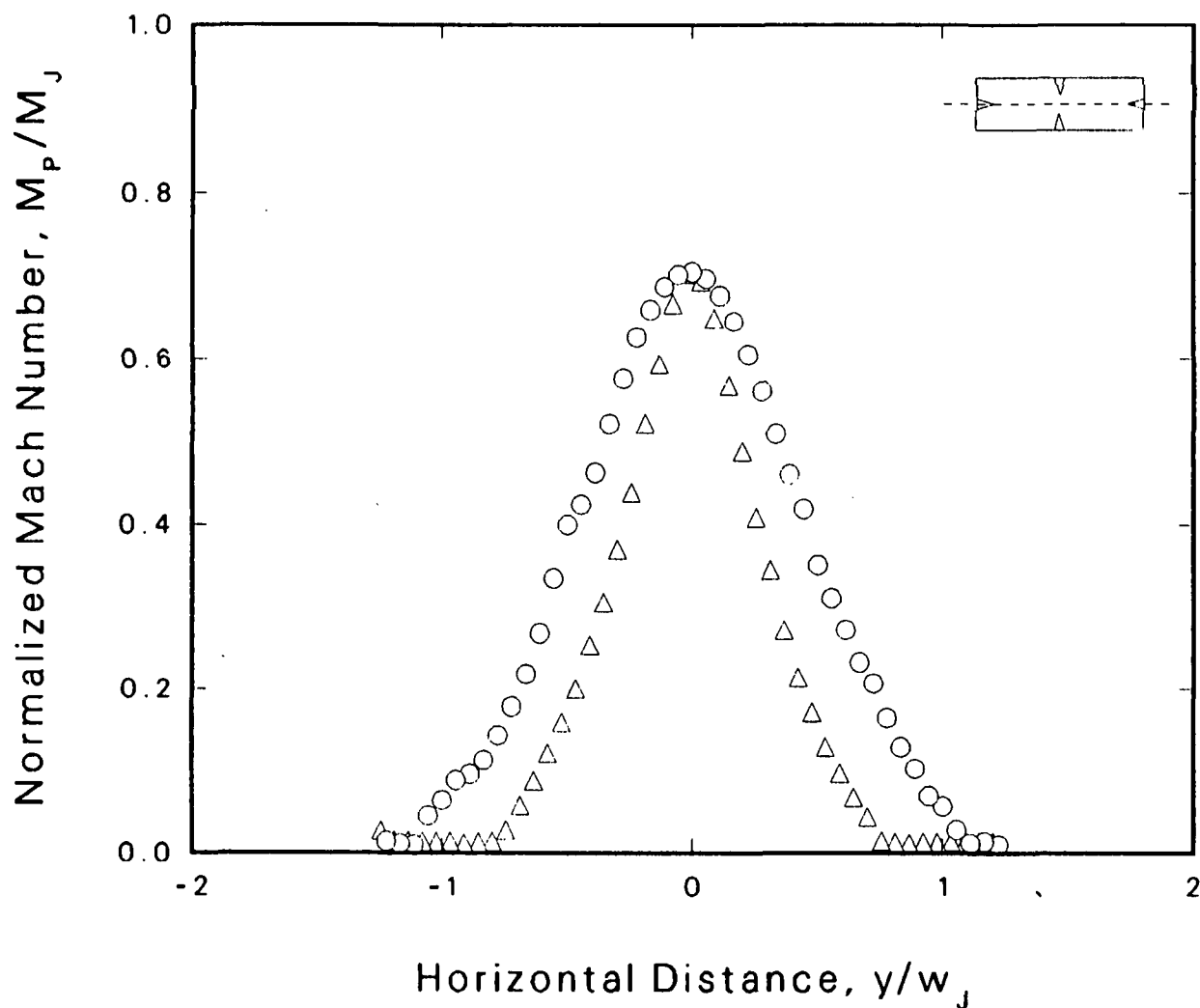
Sym	○	△
File	TAB185T	TAB191T
Config	0-0	II-A
M_j	1.148	1.149
T_{TJ}/T_A	1.01	1.01
T_{TJ}, K	283.3	283.0
U_j, mps	344.7	344.8
Re_{De}	1.831	1.837
Re_h	0.811	0.813
Re_w	3.241	3.251
p_A, kPa	98.273	98.341
T_A, K	280.4	279.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.56 Horizontal Profile for Configuration II-A
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



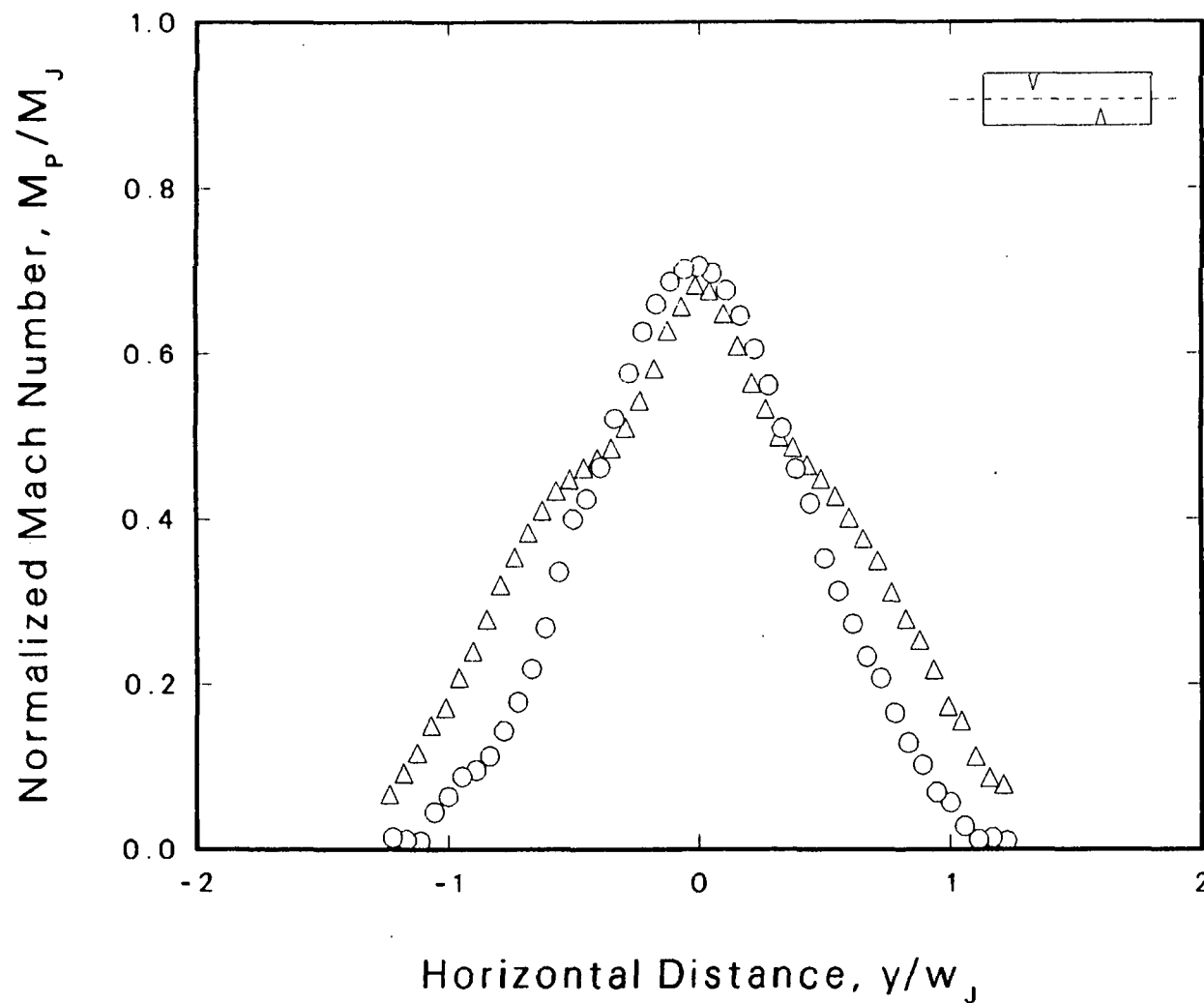
Sym	○	Δ
File	TAB185T	TAB193T
Config	0-0	IV-A
M_j	1.148	1.147
T_{Tj}/T_A	1.01	1.01
T_{Tj}, K	283.3	283.1
U_j, mps	344.7	344.5
Re_{De}	1.831	1.833
Re_h	0.811	0.812
Re_w	3.241	3.244
p_A, kPa	98.273	98.375
T_A, K	280.4	281.3
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	22.0

Figure 5.57 Horizontal Profile for Configuration IV-A
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



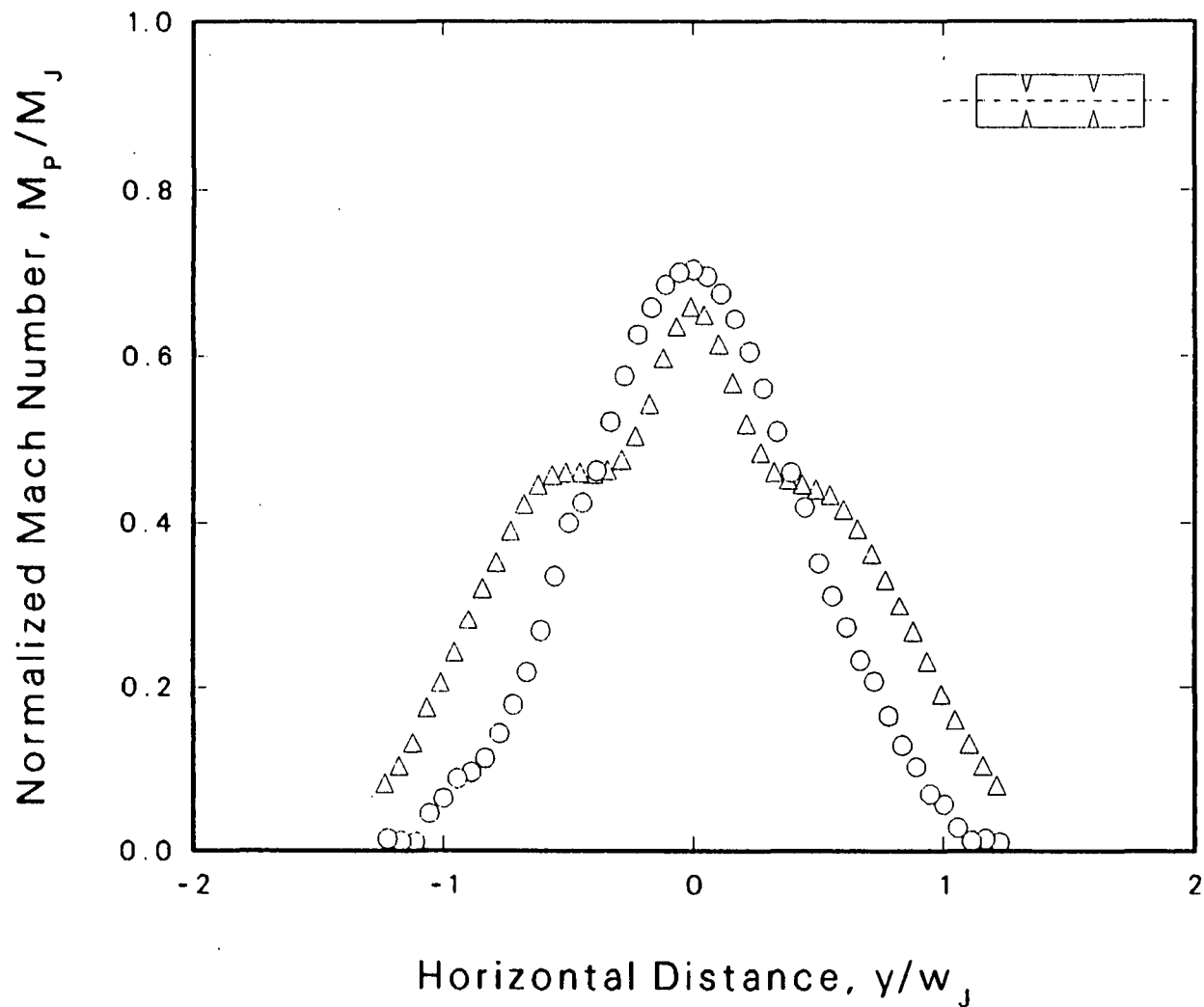
Sym	○	△
File	TAB185T	TAB278T
Config	0-0	V-C
M_j	1.148	1.147
T_{Tj}/T_A	1.01	1.00
T_{Tj} , K	283.3	279.0
U_j , mps	344.7	341.8
Re_{De}	1.831	1.870
Re_h	0.811	0.828
Re_w	3.241	3.311
p_A , kPa	98.273	98.578
T_A , K	280.4	280.2
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	0.0	2.0

Figure 5.58 Horizontal Profile for Configuration V-C
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



Sym	○	△
File	TAB185T	TAB251T
Config	0-0	VI-B
M_j	1.148	1.147
T_{Tj}/T_A	1.01	1.01
T_{Tj}, K	283.3	279.5
U_j, mps	344.7	342.1
Re_{De}	1.831	1.861
Re_h	0.811	0.824
Re_w	3.241	3.294
p_A, kPa	98.273	98.307
T_A, K	280.4	276.0
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	1.0

Figure 5.59 Horizontal Profile for Configuration VI-B
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$



Sym	○	△
File	TAB185T	TAB247T
Config	0-0	VII-B
M_j	1.148	1.148
T_{Tj}/T_A	1.01	0.98
T_{Tj}, K	283.3	281.1
U_j, mps	344.7	343.4
Re_{De}	1.831	1.829
Re_h	0.811	0.810
Re_w	3.241	3.237
p_A, kPa	98.273	97.122
T_A, K	280.4	286.9
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	1.0

Figure 5.60 Horizontal Profile for Configuration VII-B
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$

Even for this Mach number, the effect of increasing tab size was to increase the mixing, although the increase was not as dramatic as it was for the subsonic conditions. Data on the effect of tabs are shown in Figures 5.61 through 5.66 for tabs A and tabs B for configurations I through VII.

5.3.4 Effect of Tabs on the Heated Rectangular Jets

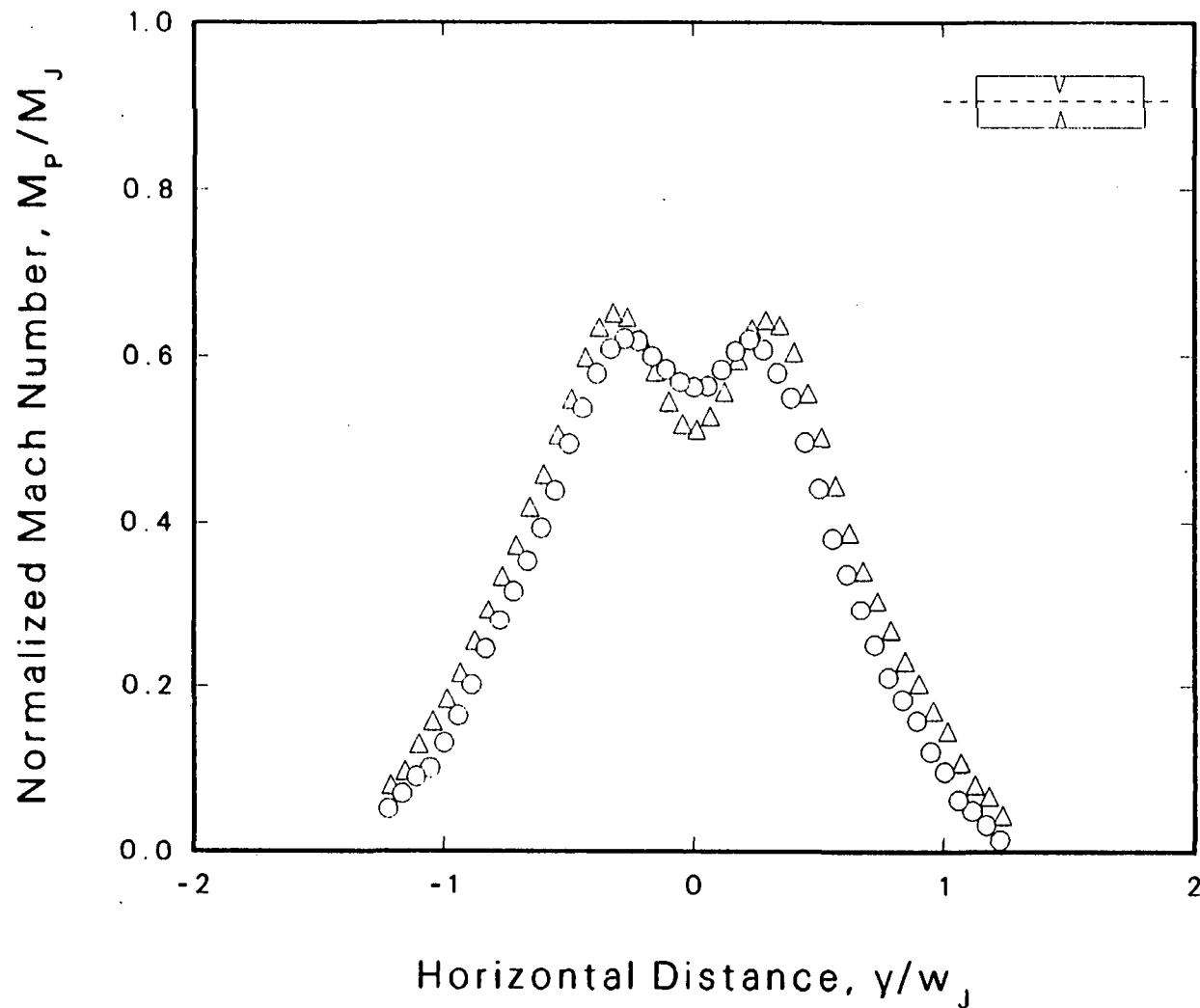
Effect of tabs on mixing enhancement of rectangular jets was similar to that of the unheated jet. This is shown in Figures 5.67 through 5.72 for measurements made along the minor and major axes, as well as along a diagonal. Peak velocities are clearly reduced in magnitude.

5.3.5 Effect of Tabs on Total Temperatures of the Jet

Consistent with the velocity data, the total temperatures of the jet, especially near the jet axis, have been reduced. Typical data are presented in Figures 5.73 through 5.78.

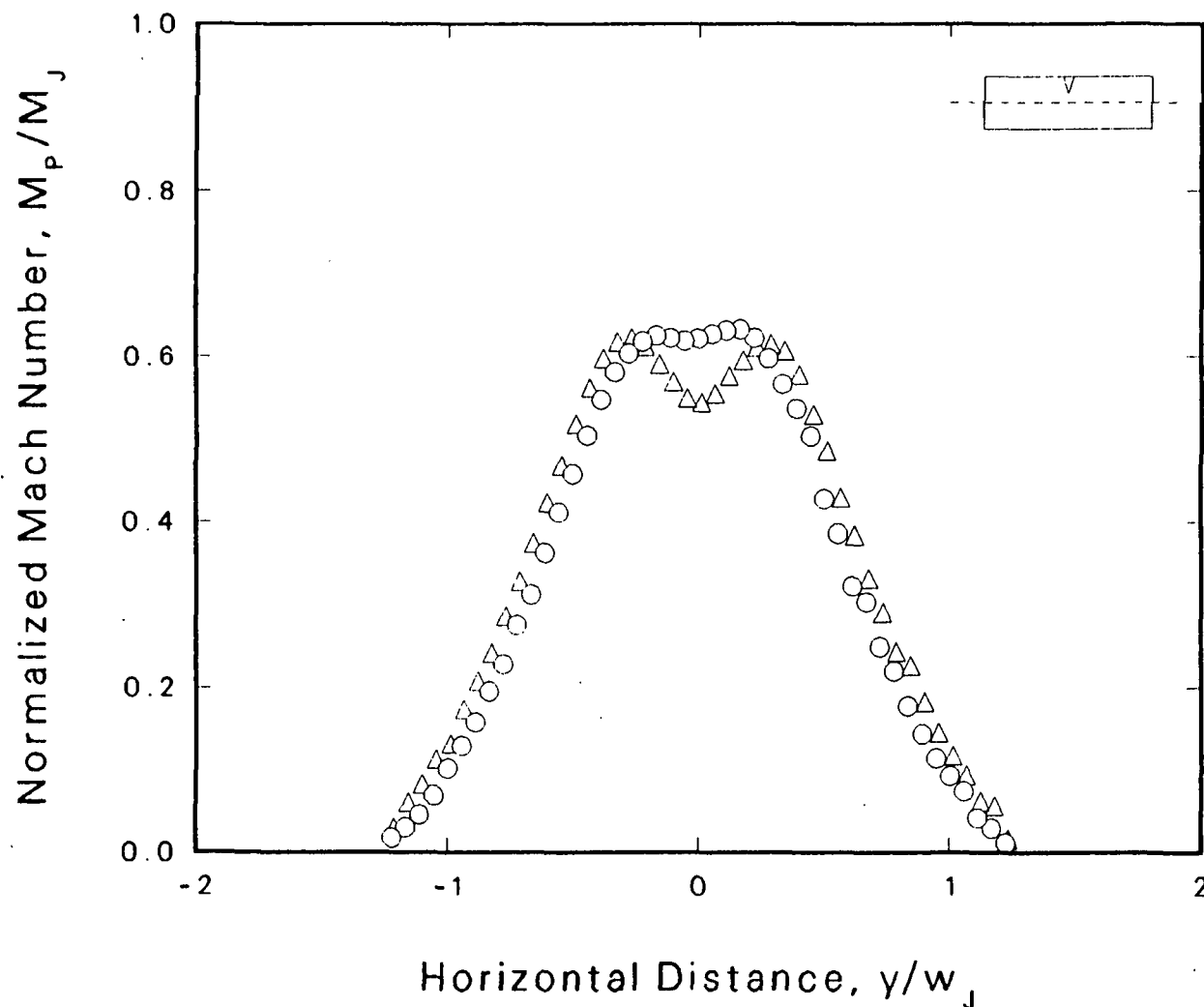
5.3.6 Mach Number and Temperature Distribution with Distance From the Jet Exit

Almost all of the data presented so far in this section was for $X/D_e = 9$, and included velocity and temperature profiles. To determine the overall performance of the jet, centerline distributions or peak distributions of the Mach numbers or temperatures can be very useful and are examined below. The profiles are presented in Appendix B.



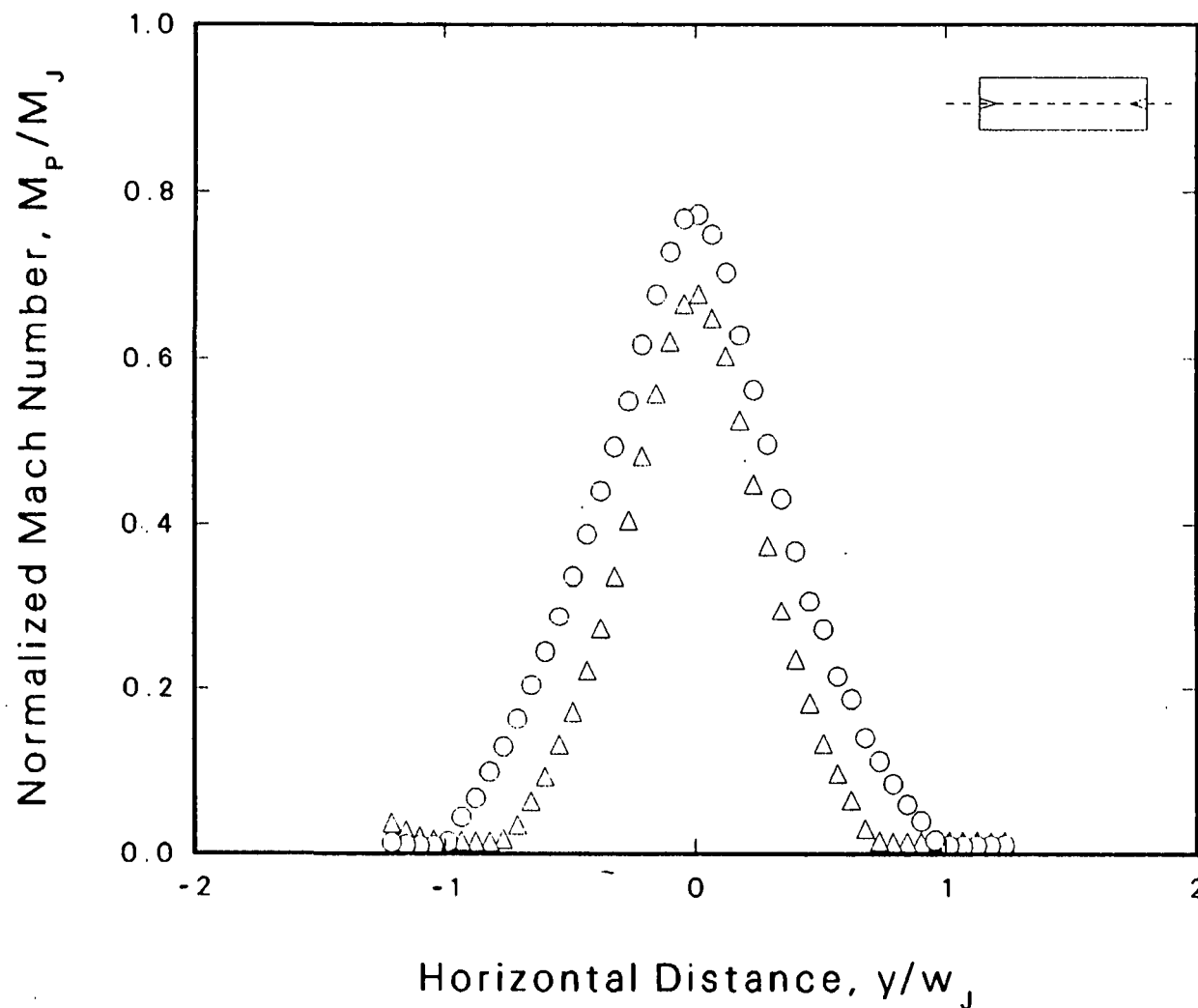
Sym	O	Δ
File	TAB187T	TAB196T
Config	I-A	I-B
M_j	1.151	1.148
T_{TJ}/T_A	0.99	1.00
T_{TJ}, K	283.9	283.7
U_j, mps	345.8	345.0
Re_{De}	1.842	1.827
Re_h	0.816	0.809
Re_w	3.261	3.233
p_A, kPa	98.781	98.205
T_A, K	286.1	284.7
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.61 Effect of Tab Size for Configuration I
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$, Horizontal



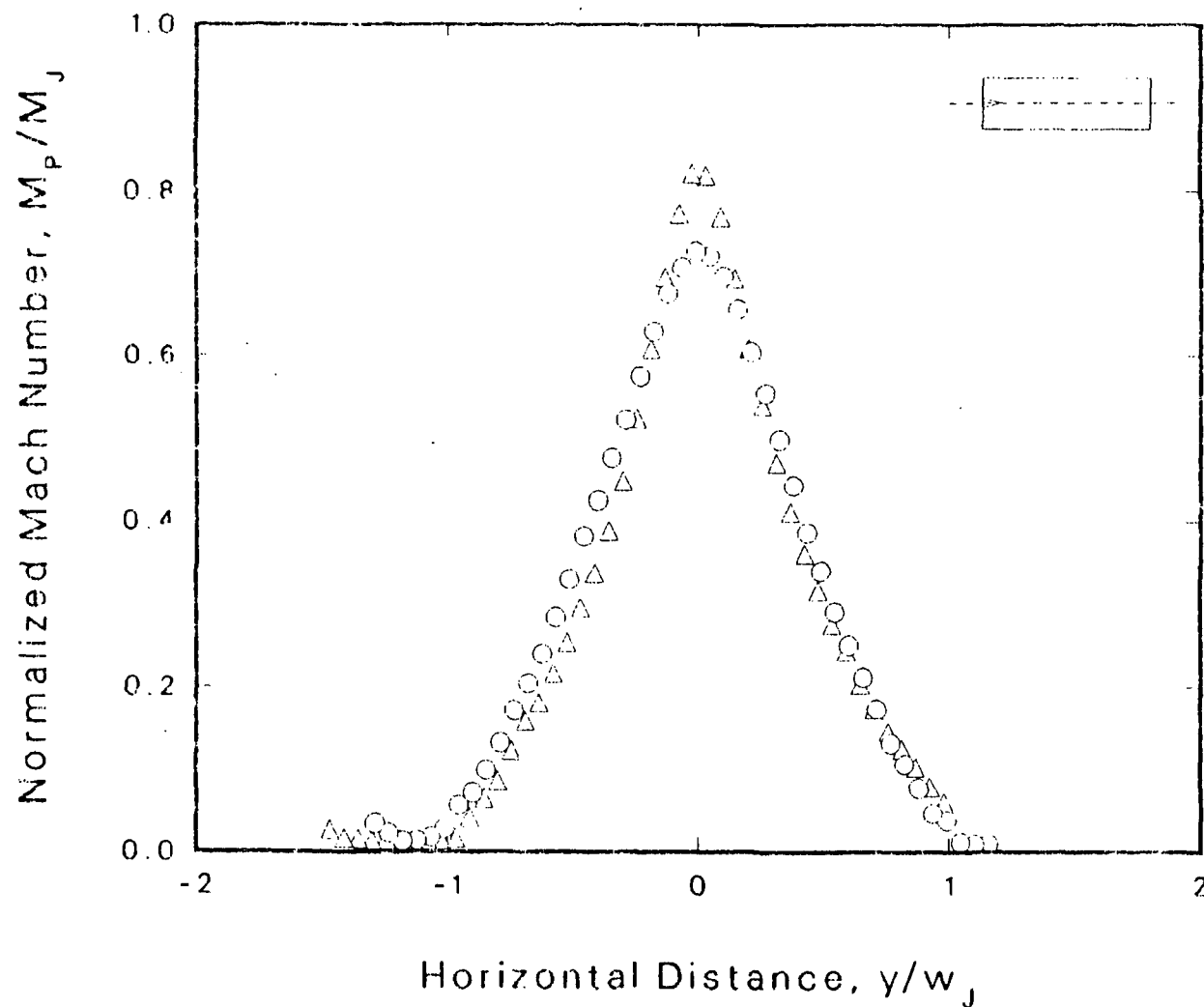
Sym	○	△
File	TAB189T	TAB198T
Config	III-A	III-B
M_j	1.147	1.147
T_{TJ}/T_A	0.99	1.02
T_{TJ}, K	284.0	282.3
U_j, mps	344.8	343.8
Re_{De}	1.827	1.843
Re_h	0.809	0.816
Re_w	3.234	3.261
p_A, kPa	98.612	98.612
T_A, K	287.5	277.2
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

Figure 5.62 Effect of Tab Size for Configuration III
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$, Horizontal Profile



Sym	○	△
File	TAB200T	TAB191T
Config	II-B	II-A
M_j	1.145	1.149
T_{Tj}/T_A	1.00	1.01
T_{Tj} , K	282.7	283.0
U_j , mps	343.7	344.8
Re_{De}	1.837	1.837
Re_h	0.813	0.813
Re_w	3.251	3.251
p_A , kPa	98.679	98.341
T_A , K	281.9	279.1
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	-1.0	-1.0

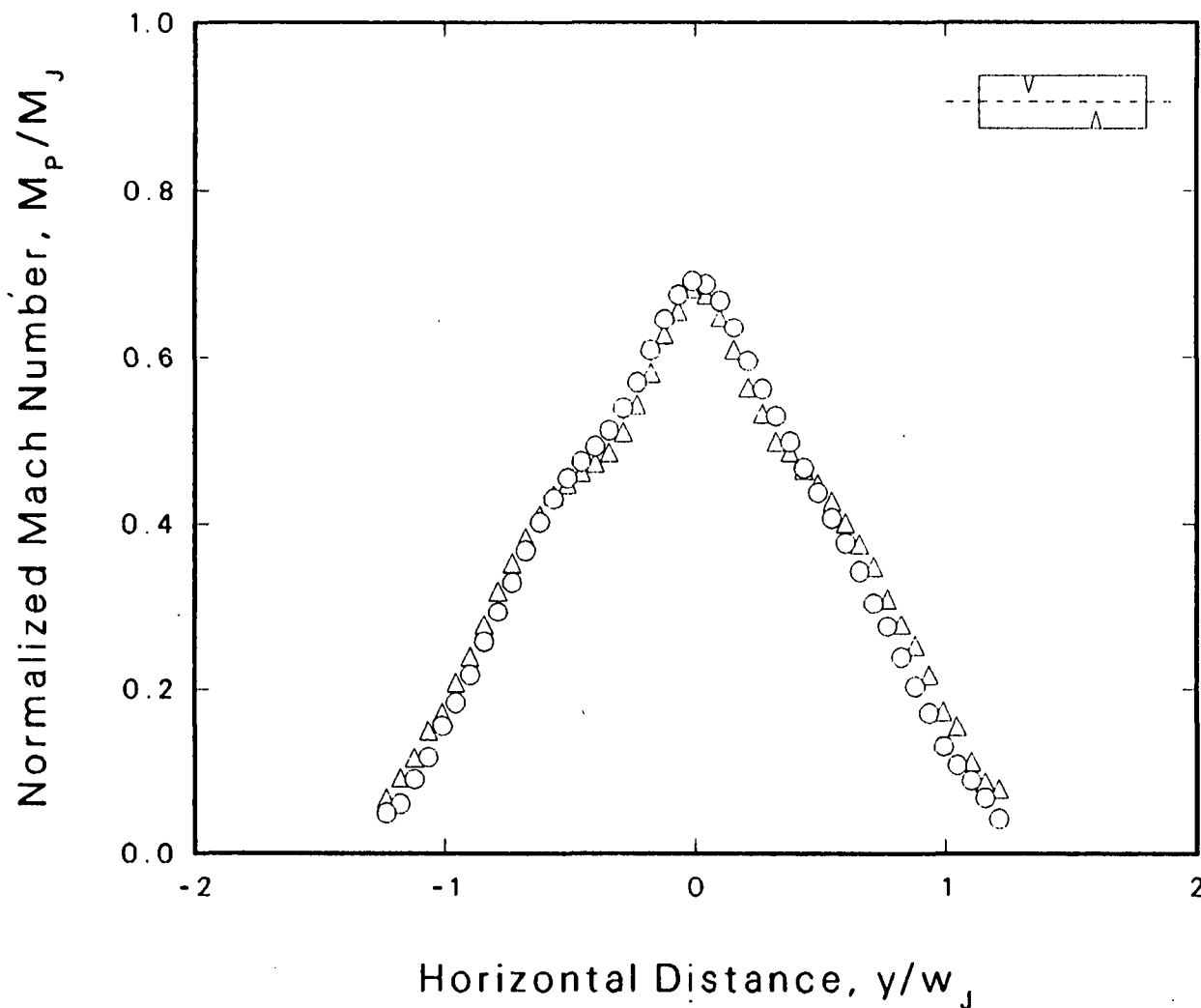
Figure 5.63 Effect of Tab Size for Configuration II
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$, Horizontal



Sym	O	Δ
File	TAB202T	TAB193T
Config	IV-B	IV-A
M_j	1.148	1.147
T_{Tj}/T_A	0.99	1.01
T_{Tj}, K	283.2	283.1
U_j, mps	344.6	344.5
Re_{De}	1.834	1.833
Re_h	0.812	0.812
Re_w	3.246	3.244
p_A, kPa	98.412	98.375
T_A, K	285.6	281.3
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	6.0	22.0

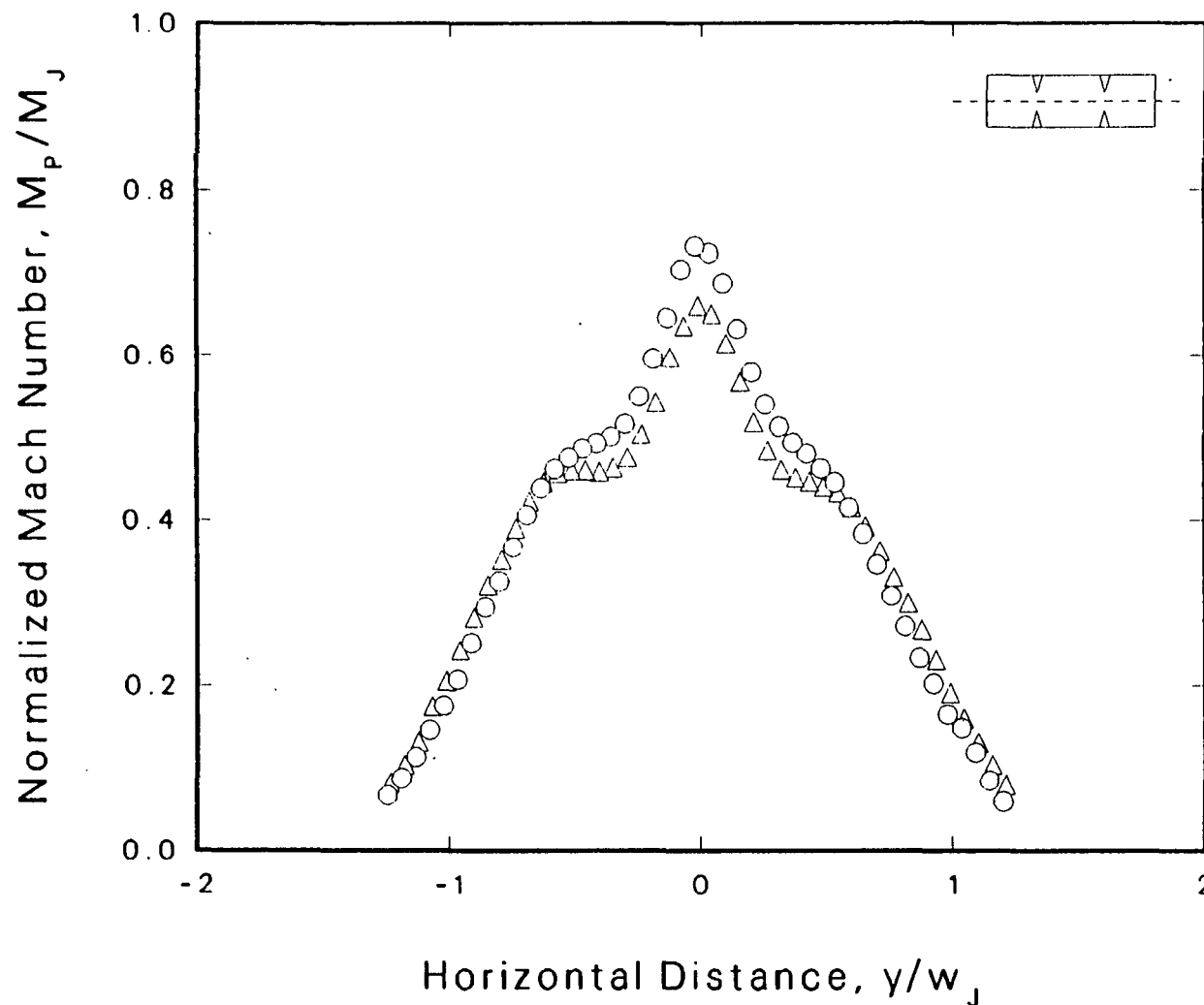
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OF POOR QUALITY

Figure 5.64 Effect of Tab Size for Configuration IV
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$, Horizontal Profile



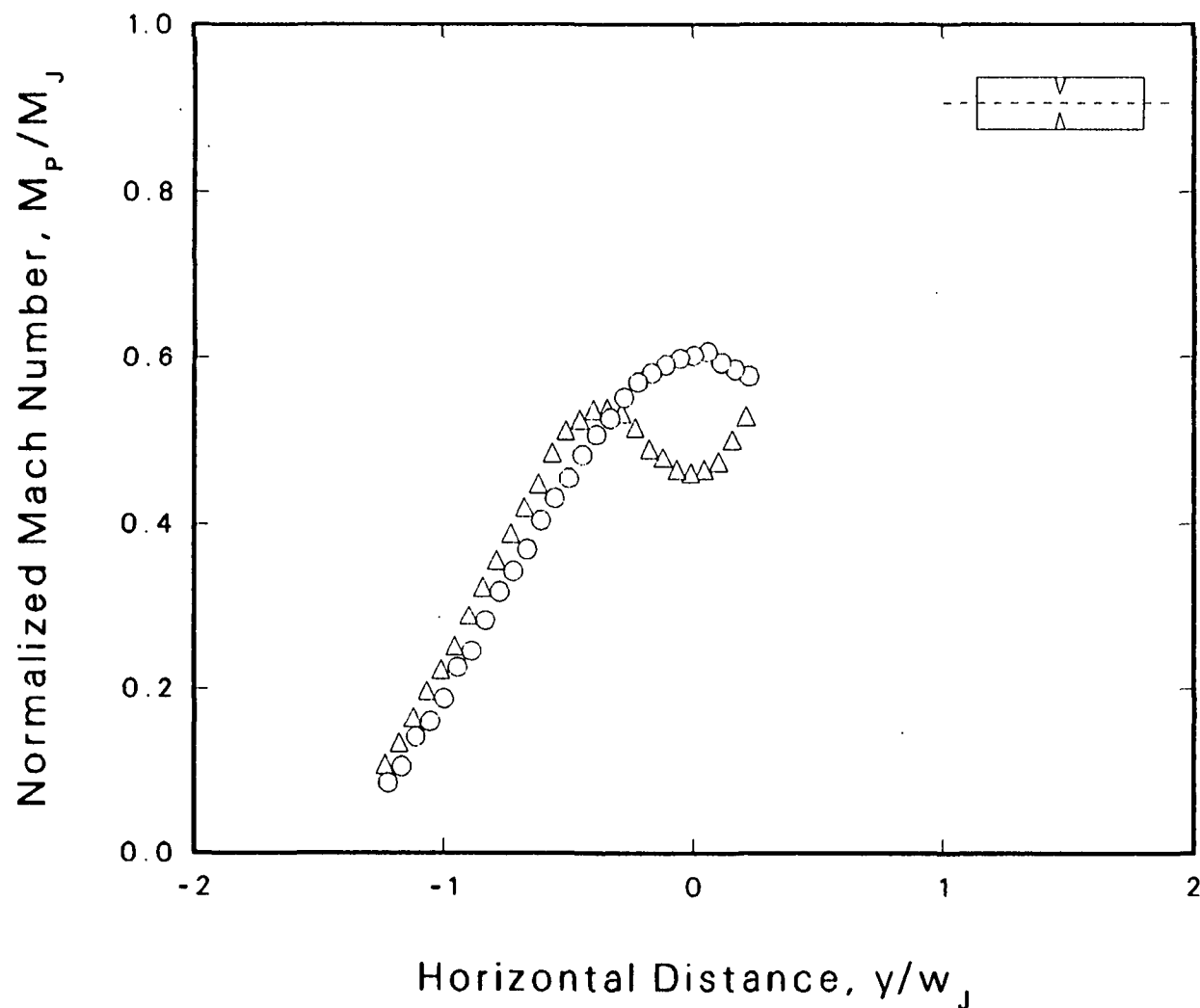
Sym	○	△
File	TAB243T	TAB251T
Config	VI-A	VI-B
M_j	1.149	1.147
T_{Tj}/T_A	0.99	1.01
T_{Tj} , K	280.7	279.5
U_j , mps	343.4	342.1
Re_{De}	1.843	1.861
Re_h	0.816	0.824
Re_w	3.263	3.294
p_A , kPa	97.596	98.307
T_A , K	282.5	276.0
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	1.0	1.0

Figure 5.65 Effect of Tab Size on Configuration VI
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$, Horizontal



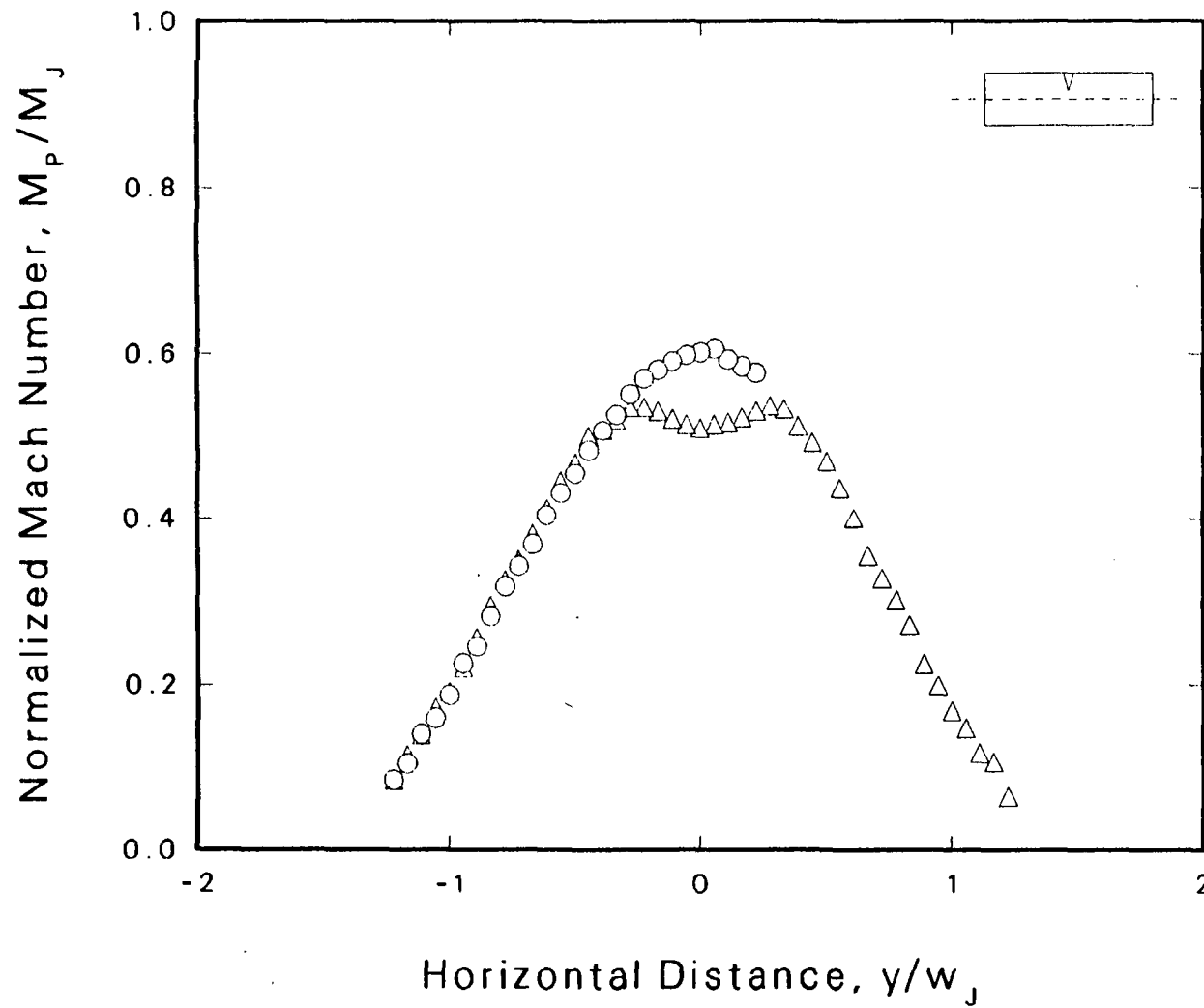
Sym	○	△
File	TAB238T	TAB247T
Config	VII-A	VII-B
M_j	1.148	1.148
T_{TJ}/T_A	0.99	0.98
T_{TJ} , K	281.1	281.1
U_j , mps	343.3	343.4
Re_{De}	1.849	1.829
Re_h	0.819	0.810
Re_w	3.273	3.237
p_A , kPa	98.239	97.122
T_A , K	285.3	286.9
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	2.0	1.0

Figure 5.66 Effect of Tab Size on Configuration VII
 $M_j=1.15$, $T_j/T_0=1$, $X/De=9$, Horizontal



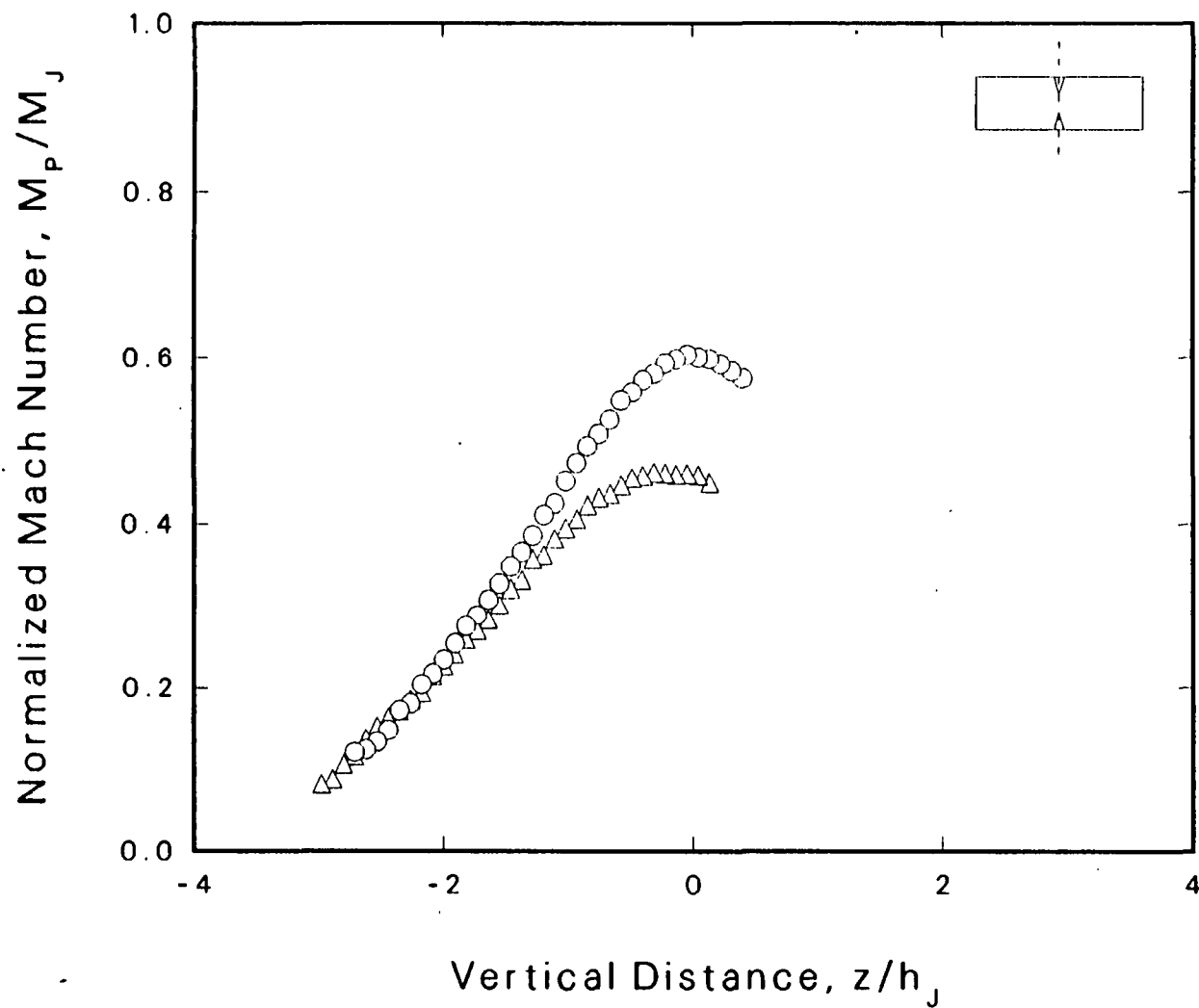
Sym	O	Δ
File	TAB332T	TAB333T
Config	0-0	I-B
M_j	0.801	0.802
T_{TJ}/T_A	2.29	2.29
T_{TJ}, K	624.8	613.9
U_j, mps	376.5	373.4
Re_{De}	0.408	0.421
Re_h	0.181	0.186
Re_w	0.723	0.745
p_A, kPa	97.968	98.815
T_A, K	272.6	268.6
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	1.0

Figure 5.67 Horizontal Profile for Configuration I-B
 $M_j=0.8$, $T_j/T_0=2.23$, $X/De=9$, Mach Number



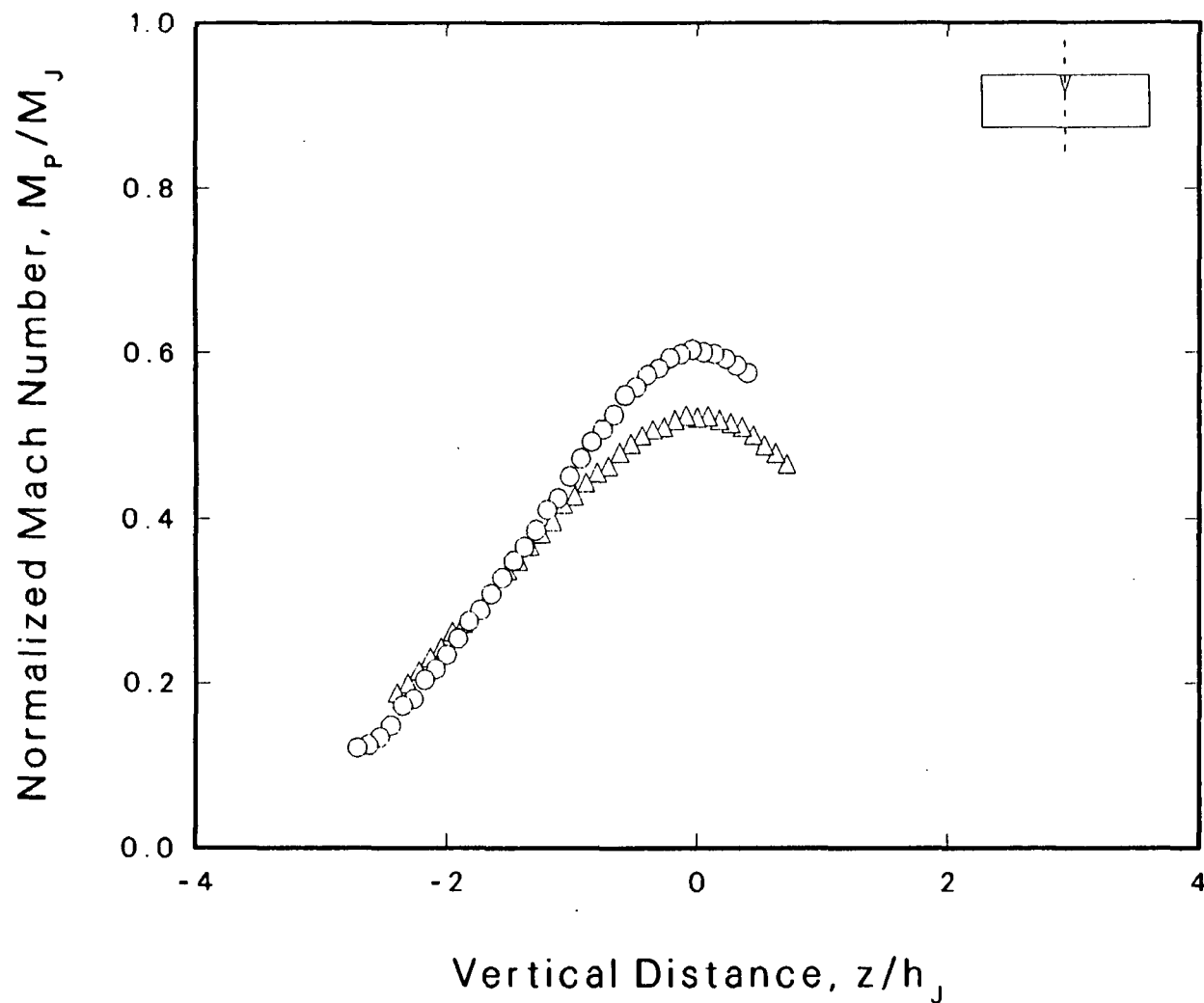
Sym	○	△
File	TAB332T	TAB336T
Config	0-0	III-B
M_j	0.801	0.802
T_{Tj}/T_A	2.29	2.28
T_{Tj}, K	624.8	629.1
U_j, mps	376.5	377.9
Re_{De}	0.408	0.409
Re_h	0.181	0.181
Re_w	0.723	0.723
p_A, kPa	97.968	98.849
T_A, K	272.6	275.4
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 5.68 Horizontal Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=2.23$, $X/De=9$, Mach Number



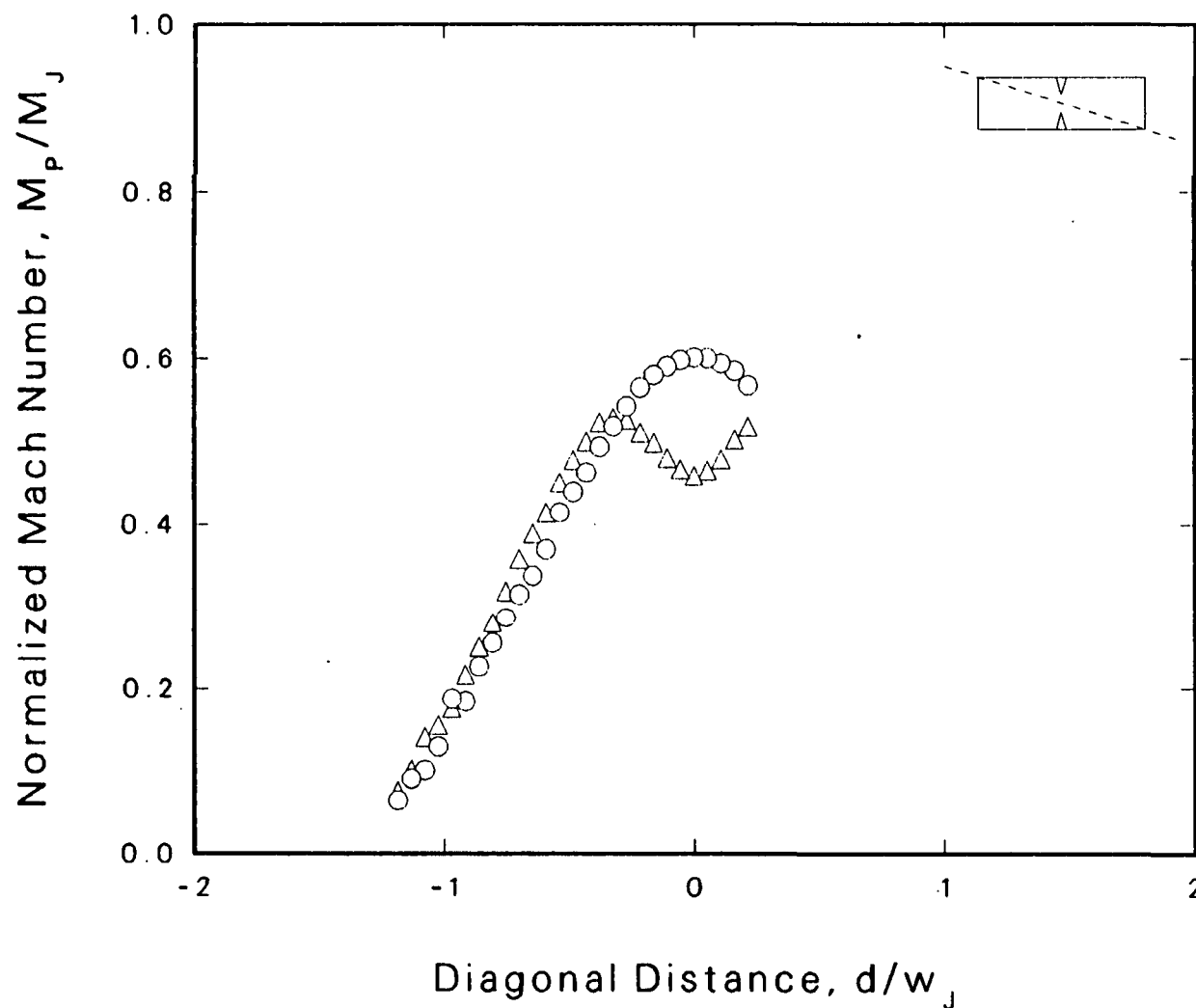
Sym	(O)	(Δ)
File	TAB331T	TAB334T
Config	0-0	I-B
M_j	0.802	0.801
T_{Tj}/T_A	2.29	2.28
T_{Tj} , K	621.9	615.2
U_j , mps	375.9	373.4
Re_{De}	0.411	0.419
Re_h	0.182	0.186
Re_w	0.727	0.742
p_A , kPa	98.002	98.815
T_A , K	272.0	269.8
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	1.0	7.0

Figure 5.69 Vertical Profile for Configuration I-B
 $M_j=0.8$, $T_j/T_0=2.23$, $X/De=9$, Mach Number



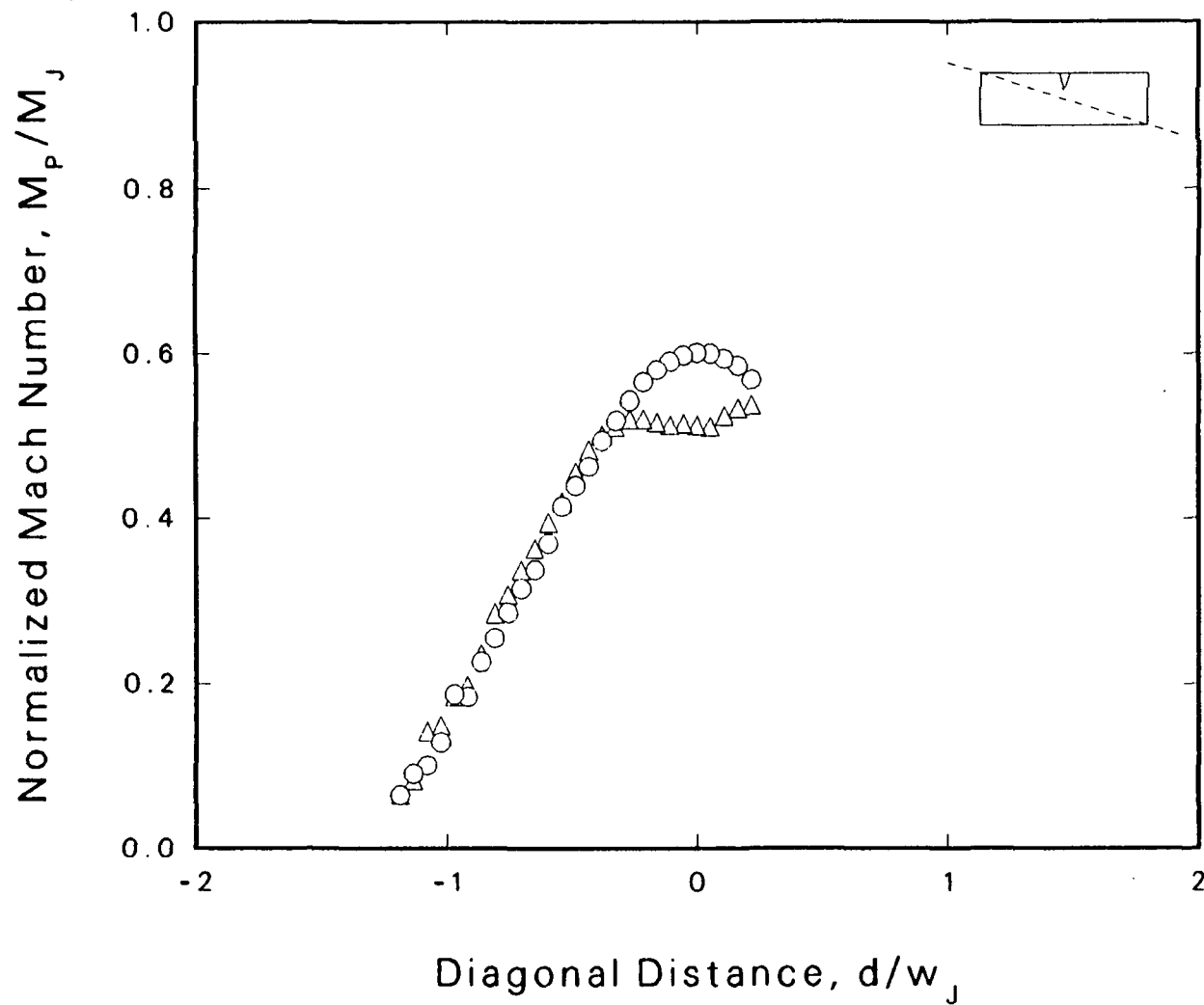
Sym	O	Δ
File	TAB331T	TAB335T
Config	0-0	III-B
M_J	0.802	0.801
T_{TJ}/T_A	2.29	2.27
T_{TJ}, K	621.9	616.3
U_J, mps	375.9	373.9
Re_{De}	0.411	0.419
Re_h	0.182	0.185
Re_w	0.727	0.741
p_A, kPa	98.002	98.849
T_A, K	272.0	271.5
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Y/w_J	0.00	0.00
$\Delta Z, mm$	1.0	-6.0

Figure 5.70 Vertical Profile for Configuration III-B
 $M_J=0.8$, $T_J/T_0=2.23$, $X/De=9$, Mach Number



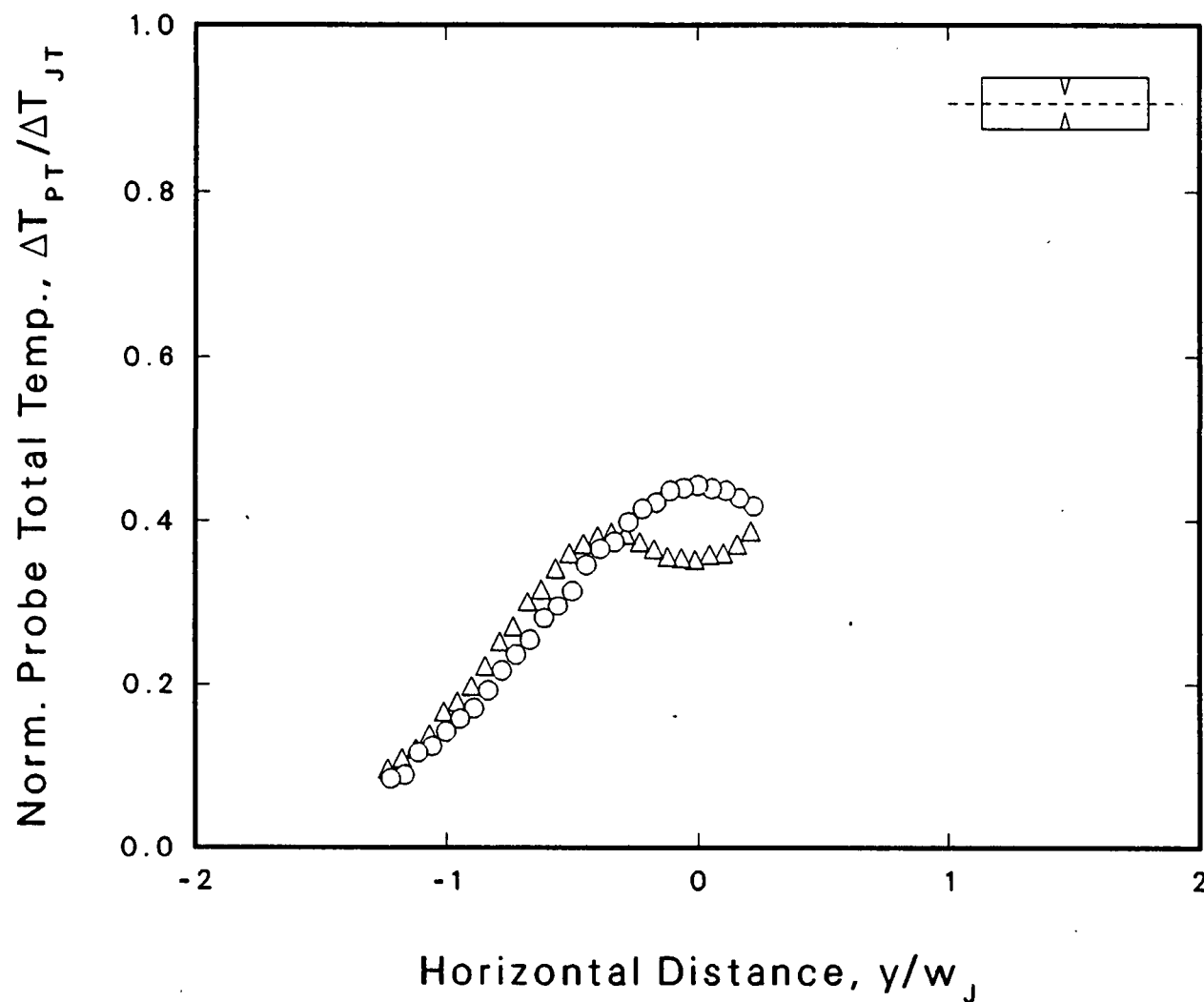
Sym	O	Δ
File	TAB346T	TAB347T
Config	0-0	I-B
M_J	0.803	0.805
T_{TJ}/T_A	2.29	2.29
T_{TJ}, K	641.5	661.2
U_J, mps	382.1	388.3
Re_{De}	0.395	0.382
Re_h	0.175	0.169
Re_w	0.720	0.696
p_A, kPa	97.494	97.596
T_A, K	280.5	288.3
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 5.71 Diagonal Profile for Configuration I-B
 $M_J=0.8$, $T_J/T_0=2.23$, $X/De=9$, -14 deg, Mach Number



Sym	○	△
File	TAB346T	TAB348T
Config	0-0	III-B
M_j	0.803	0.804
T_{TJ}/T_A	2.29	2.30
T_{TJ}, K	641.5	664.3
U_j, mps	382.1	389.2
Re_{De}	0.395	0.379
Re_h	0.175	0.168
Re_w	0.720	0.692
p_A, kPa	97.494	97.596
T_A, K	280.5	288.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 5.72 Diagonal Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=2.23$, $X/De=9$, -14 deg, Mach Number



Sym	O	Δ
File	TAB332T	TAB333T
Config	0-0	I-B
M_J	0.801	0.802
T_{TJ}/T_A	2.29	2.29
T_{TJ}, K	624.8	613.9
U_J, mps	376.5	373.4
Re_{De}	0.408	0.421
Re_h	0.181	0.186
Re_w	0.723	0.745
p_A, kPa	97.968	98.815
T_A, K	272.6	268.6
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	1.0

Figure 5.73 Horizontal Temperature Profile for Config I-B
 $M_J=0.8$, $T_J/T_0=2.3$, $X/De=9$

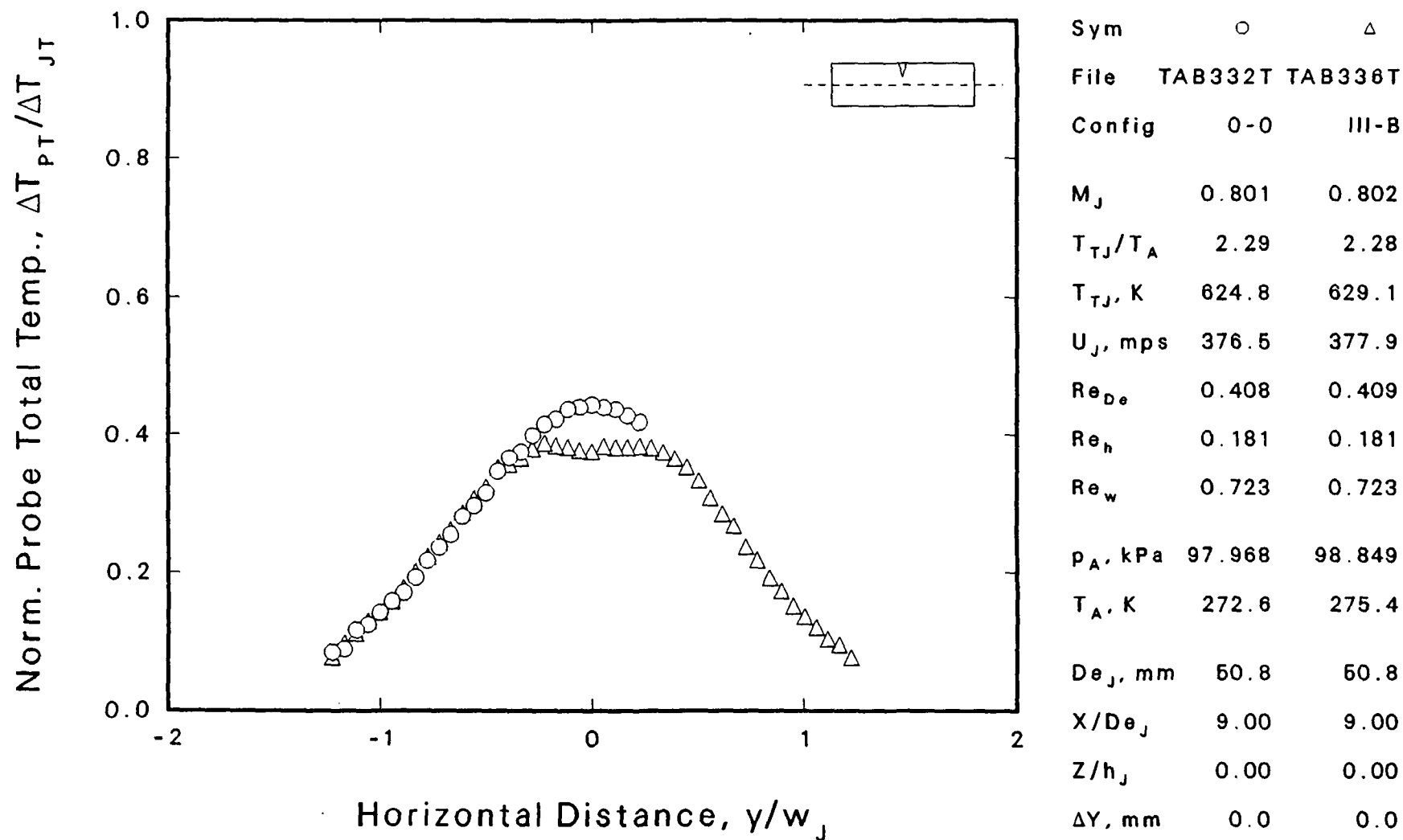
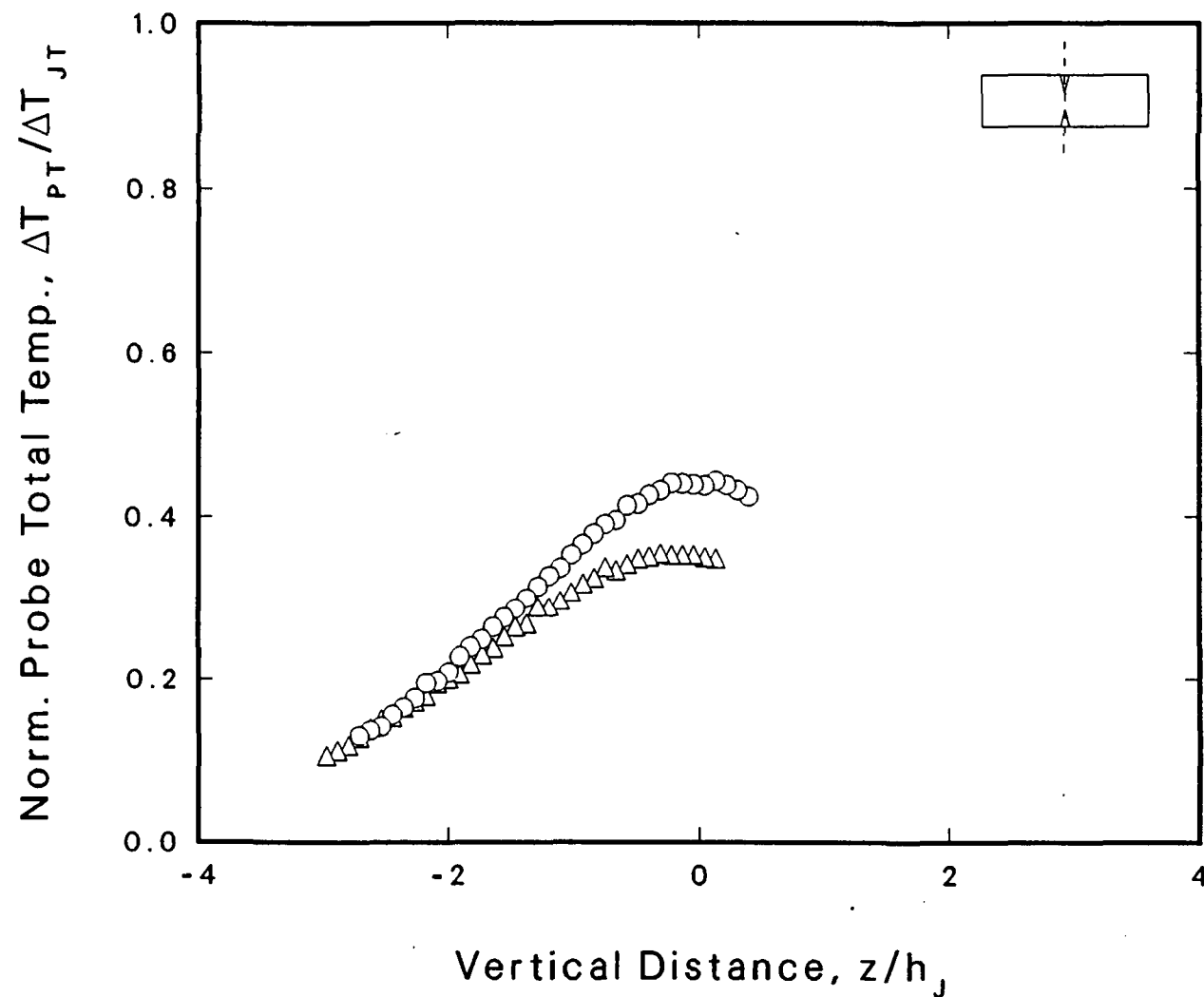
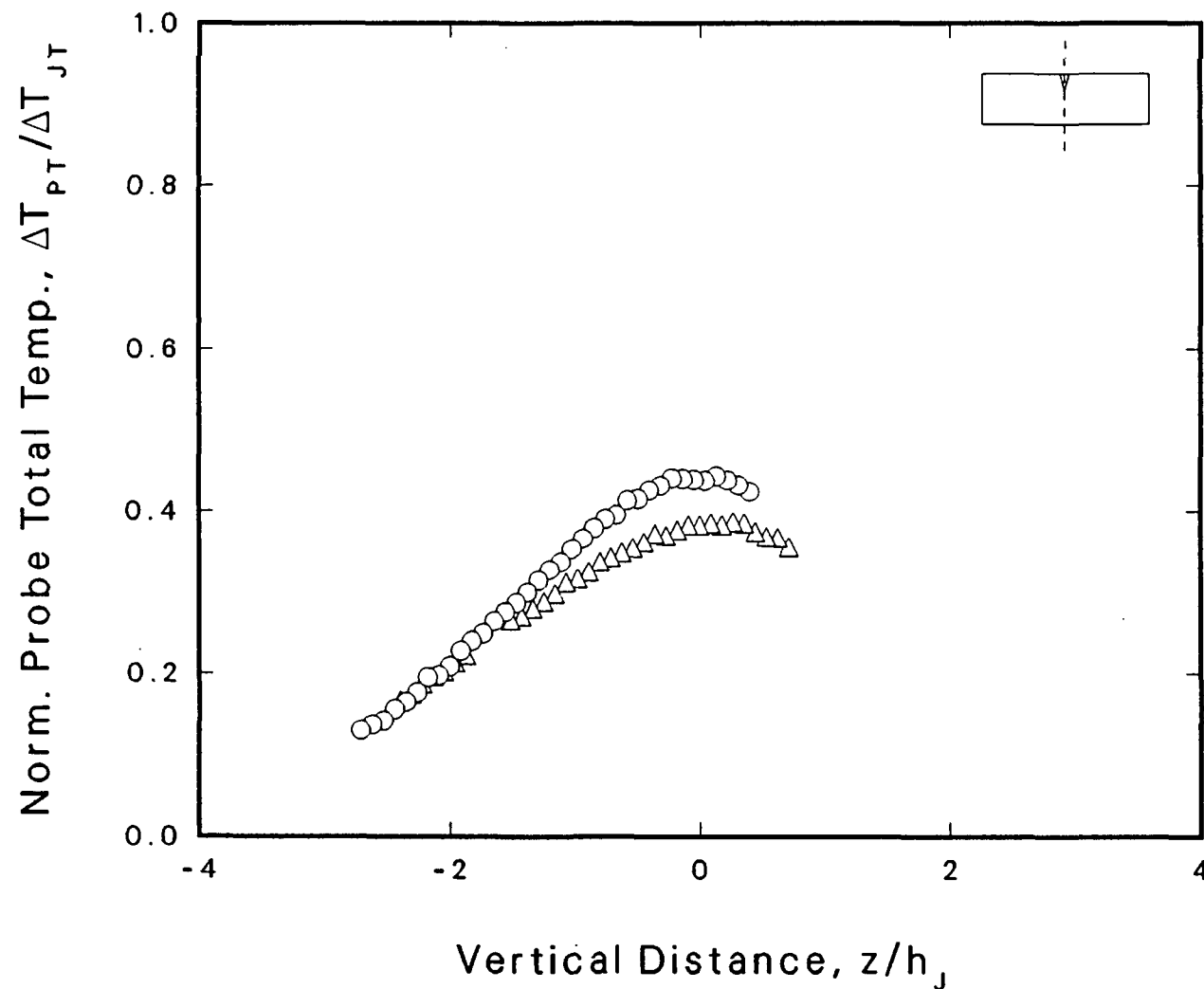


Figure 5.74 Horizontal Temperature Profile for Configuration III-B
 $M_J=0.8$, $T_J/T_0=2.3$, $X/De=9$



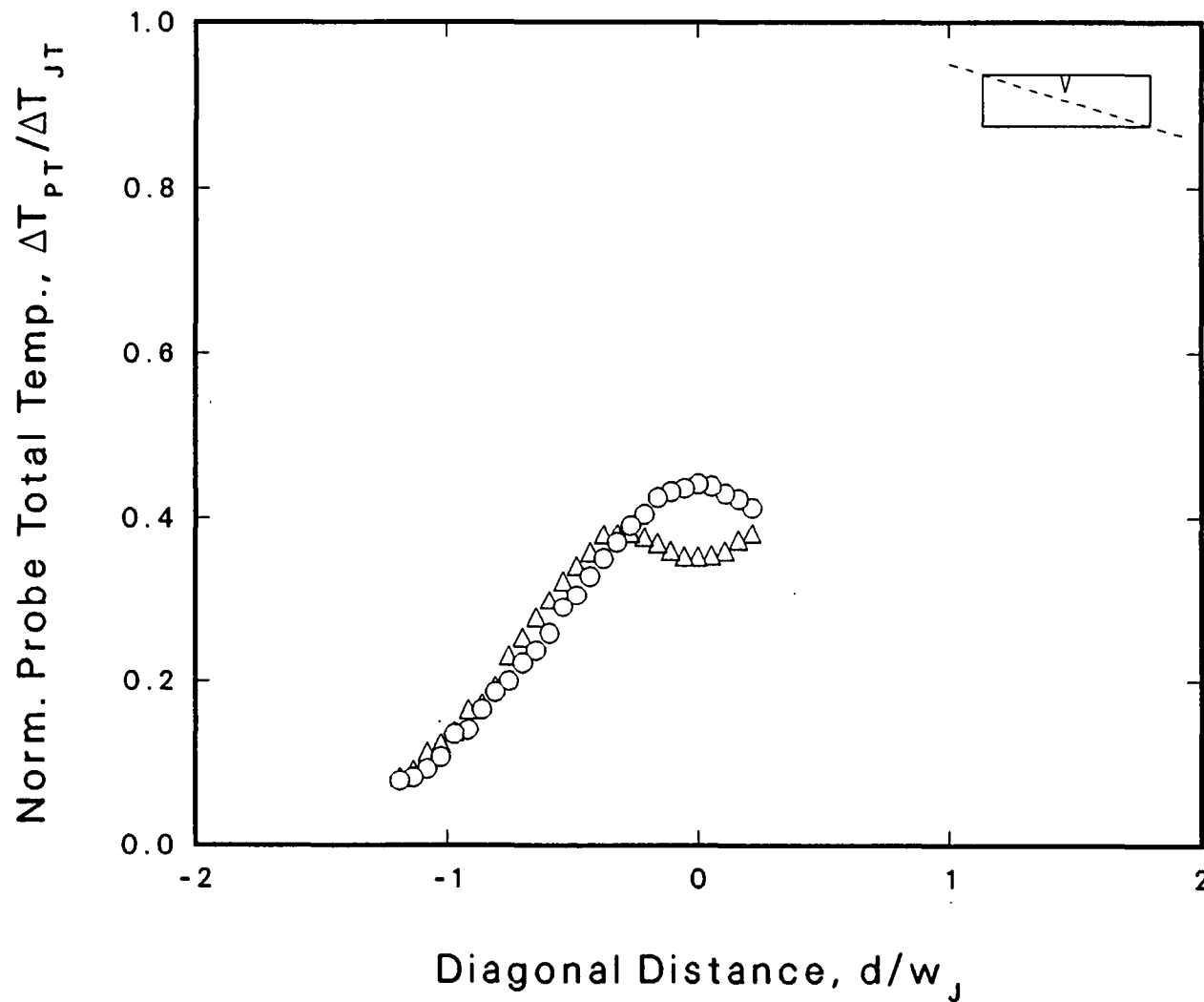
Sym	O	Δ
File	TAB331T	TAB334T
Config	0-0	I-B
M_J	0.802	0.801
T_{TJ}/T_A	2.29	2.28
T_{TJ}, K	621.9	615.2
U_J, mps	375.9	373.4
Re_{De}	0.411	0.419
Re_h	0.182	0.186
Re_w	0.727	0.742
p_A, kPa	98.002	98.815
T_A, K	272.0	269.8
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Y/w_J	0.00	0.00
$\Delta Z, mm$	1.0	7.0

Figure 5.75 Vertical Temperature Profile for Config I-B
 $M_J=0.8$, $T_J/T_0=2.3$, $X/De=9$



Sym	○	△
File	TAB331T	TAB335T
Config	0-0	III-B
M_J	0.802	0.801
T_{TJ}/T_A	2.29	2.27
T_{TJ}, K	621.9	616.3
U_J, mps	375.9	373.9
Re_{De}	0.411	0.419
Re_h	0.182	0.185
Re_w	0.727	0.741
p_A, kPa	98.002	98.849
T_A, K	272.0	271.5
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Y/w_J	0.00	0.00
$\Delta Z, mm$	1.0	-6.0

Figure 5.76 Vertical Temperature Profile for Config III-B
 $M_J=0.8$, $T_J/T_0=2.3$, $X/De=9$



Sym	O	Δ
File	TAB346T	TAB347T
Config	0-0	III-B
M_J	0.803	0.805
T_{TJ}/T_A	2.29	2.29
T_{TJ}, K	641.5	661.2
U_J, mps	382.1	388.3
Re_{De}	0.395	0.382
Re_h	0.175	0.169
Re_w	0.720	0.696
p_A, kPa	97.494	97.596
T_A, K	280.5	288.3
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure 5.77 Diagonal Temperature Profile for Config I-B
 $M_J=0.8$, $T_J/T_0=2.3$, $X/De=9$, -14 deg.

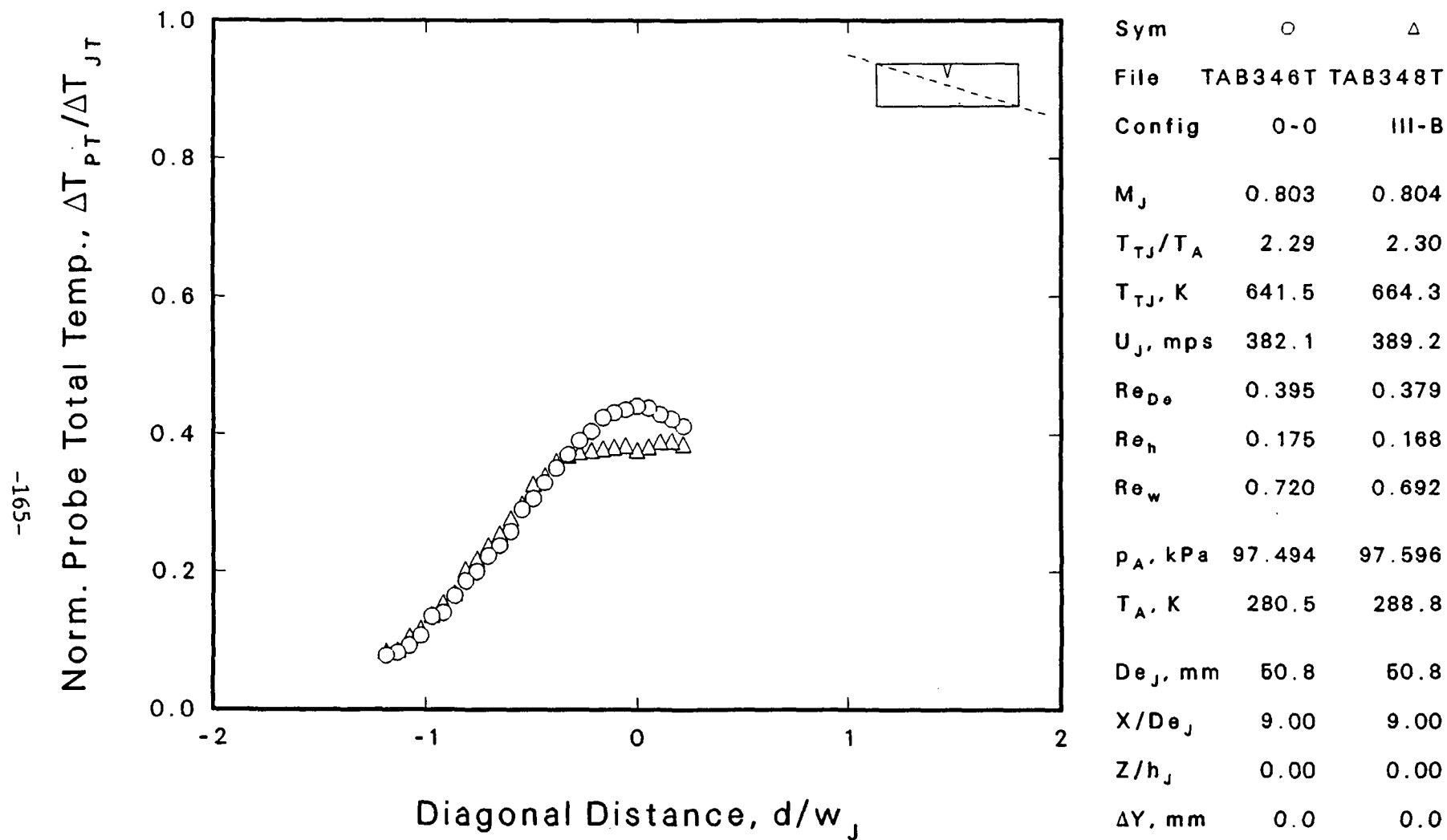


Figure 5.78 Diagonal Temperature Profile for Configuration III-B
 $M_j=0.8$, $T_j/T_0=2.3$, $X/D_e=9$

The effect of the vertical centerline tab configurations on the centerline and peak Mach number ratios is shown in Figure 5.79 and 5.80, respectively. At $X/D_e = 15$, the ratios are about equal whether measured on the centerline or at the peak of the profile. But, at lower values of X/D_e , e.g. 5, there is a great difference between the effects measured on the centerline and at the peak. The level of the peak value in the Mach number profile may be a better indicator of the overall amount of mixing that has taken place in the jet. For this reason, the Mach number ratio of the peak profile values has been used in assessing the performance of the various tab configurations later in this section.

It should be noted that as the distance from the nozzle exit increases, the difference between the two-tab and one-tab configurations diminishes. Also, the maximum benefit of tabs does not vary a great deal at X/D_e positions between about 5 and 15, as shown in Figure 5.80.

5.4 Overall Assessment of the Performance of Tabs with Rectangular Jets

In general, it was found that there are configurations that do provide beneficial effects for both temperature and Mach number. Typical results are summarized in Figure 5.81 where the tabs reduced the temperature and Mach numbers relative to the baseline configuration at all axial locations.

As shown in Figure 5.81, configurations I-B, I-C, and III-B have improved performance relative to the baseline jet when the jet is heated. There is little difference in the improvement produced by the tabs except for configuration I-C which is noticeably better than both of the other two configurations.

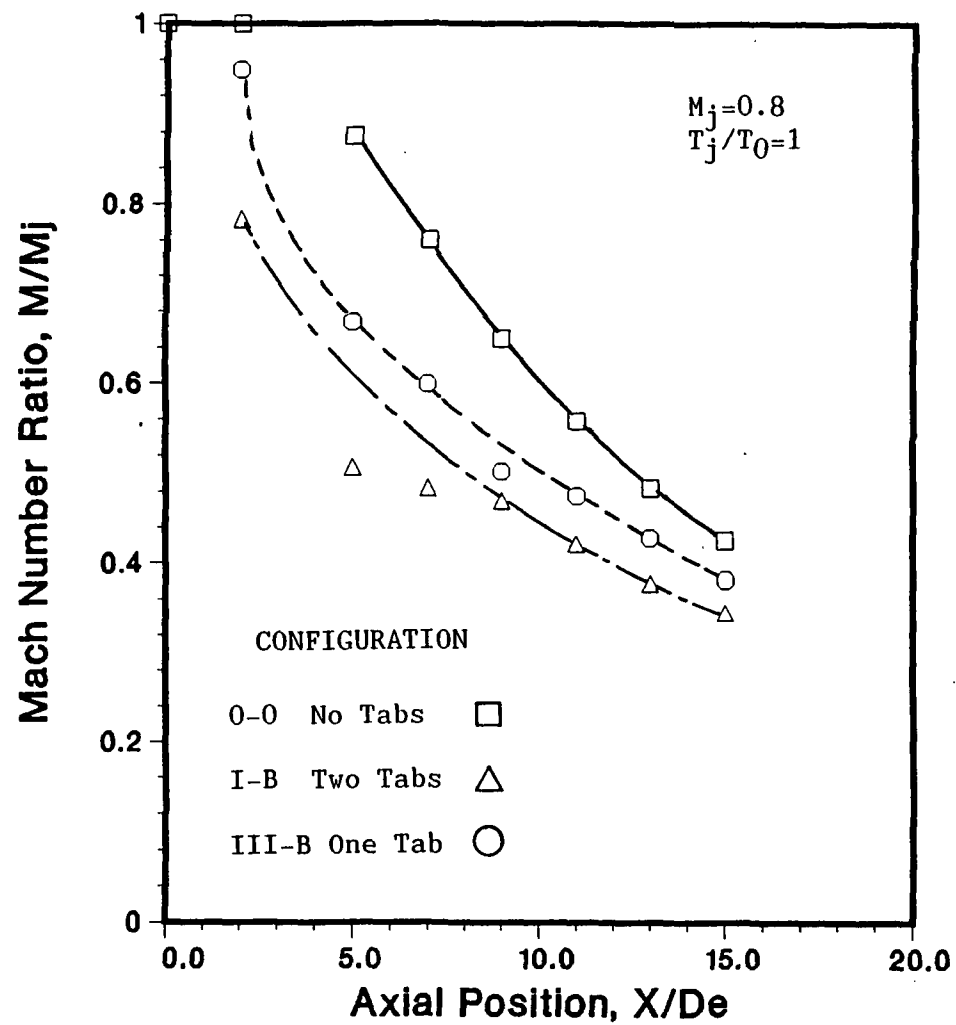


Figure 5.79 Effect of Tabs on Axial Decay of Centerline Jet Mach Number - Unheated Jet

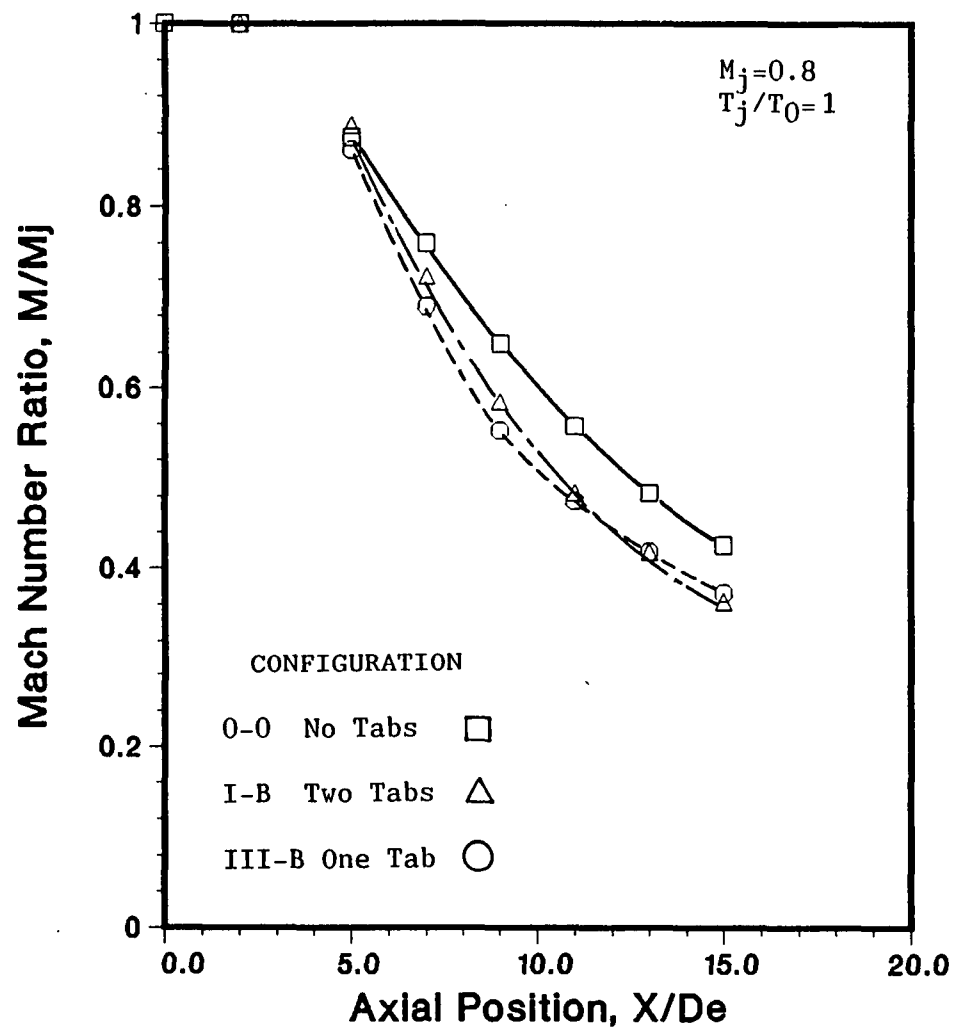


Figure 5.80 Effect of Tabs on Axial Decay of Peak Jet Mach Number - Unheated Jet

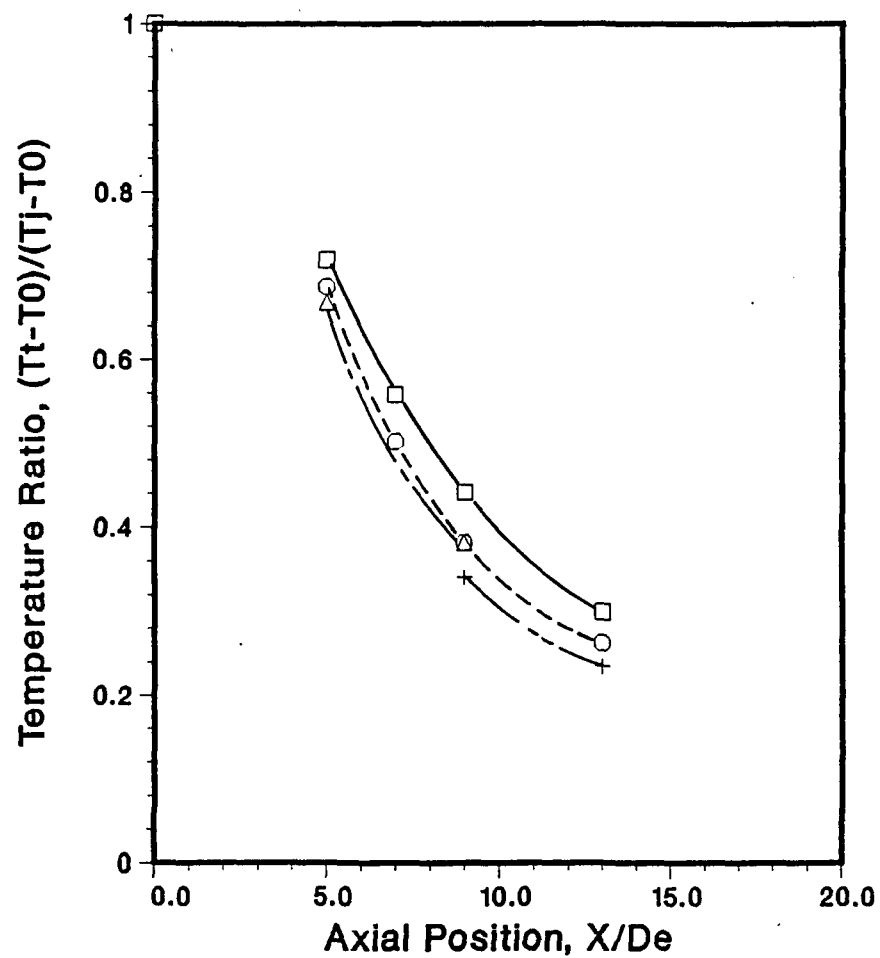
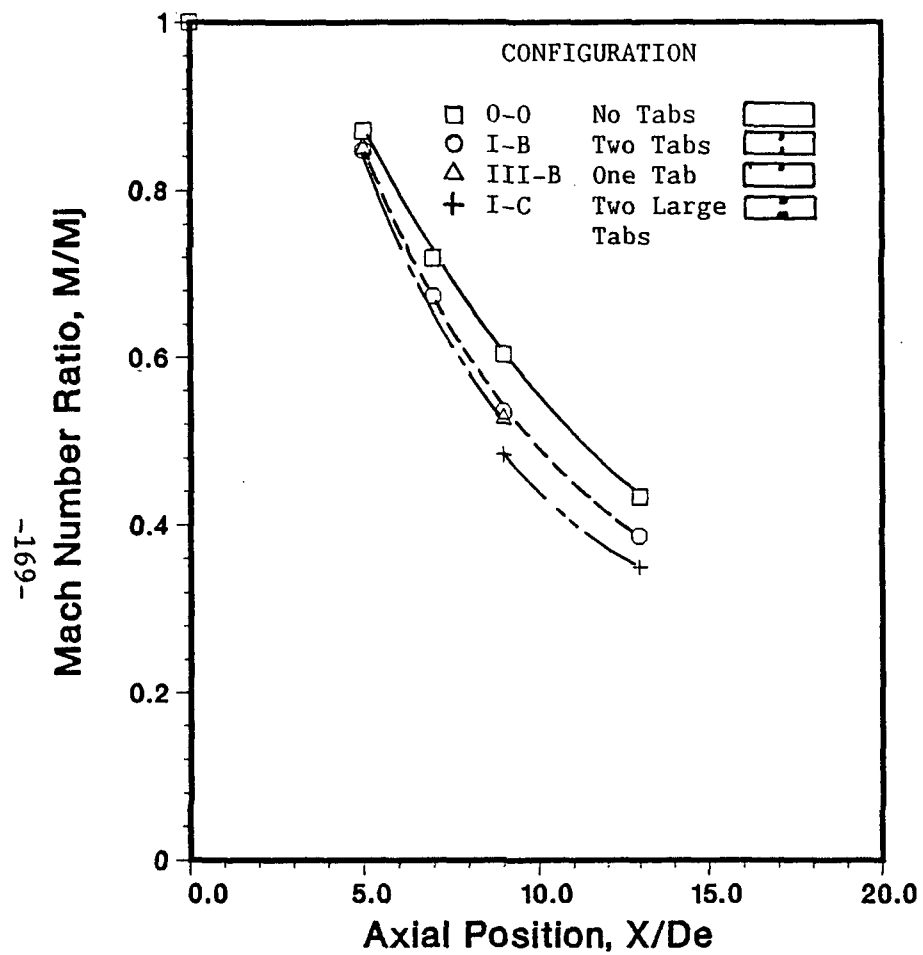


Figure 5.81 Effect of Tabs on Axial Decay of Peak Jet Mach Number and Total Temperature, $M_j=0.8$, $T_j/T_0=2.3$

As mentioned in Section 4, even without tabs, rectangular jets mix much faster than round jets. As shown in Figure 5.82, further mixing enhancement can be obtained when tabs are used.

It should also be remarked that the rectangular jets with two tabs provided better performance than a round jet also fitted with two tabs, based on centerline velocity profiles as shown in Figure 5.83. However, based on peak velocity profiles, this may not be the case. Data are not available for the round nozzle at $X/D < 9$ to validate this statement.

5.5 Concluding Comments

It is appropriate here to summarize the results. In all, fourteen configurations were evaluated at $M_j = 0.8$ and 1.15 at $X/D_e = 9$. The peaks of the measured Mach number profile are presented as ratios to the peaks of the baseline Mach number profiles in Figure 5.84. In that figure, a ratio of one indicates that the peak for the test configuration is of the same level as the peak of the baseline configuration, that is: no tabs. Ratios smaller than unity represent better mixing than the baseline nozzle while ratios greater than unity represent poorer performance. The peak value is used because it provides a conservative measure of the effects of the tabs on the flow. Centerline profiles, on the other hand, present an overly optimistic picture of the benefits of those configurations that have tabs in the center of the long axis of the nozzles.

Clearly, it can be claimed that, in terms of enhanced mixing, rectangular jets are by themselves better than round jets. Mixing can be further enhanced by suitable choices of tabs and tab configurations. Unfortunately, this study was not comprehensive enough to make firm conclusions about the most optimum configuration or the tab size. Further work is clearly warranted.

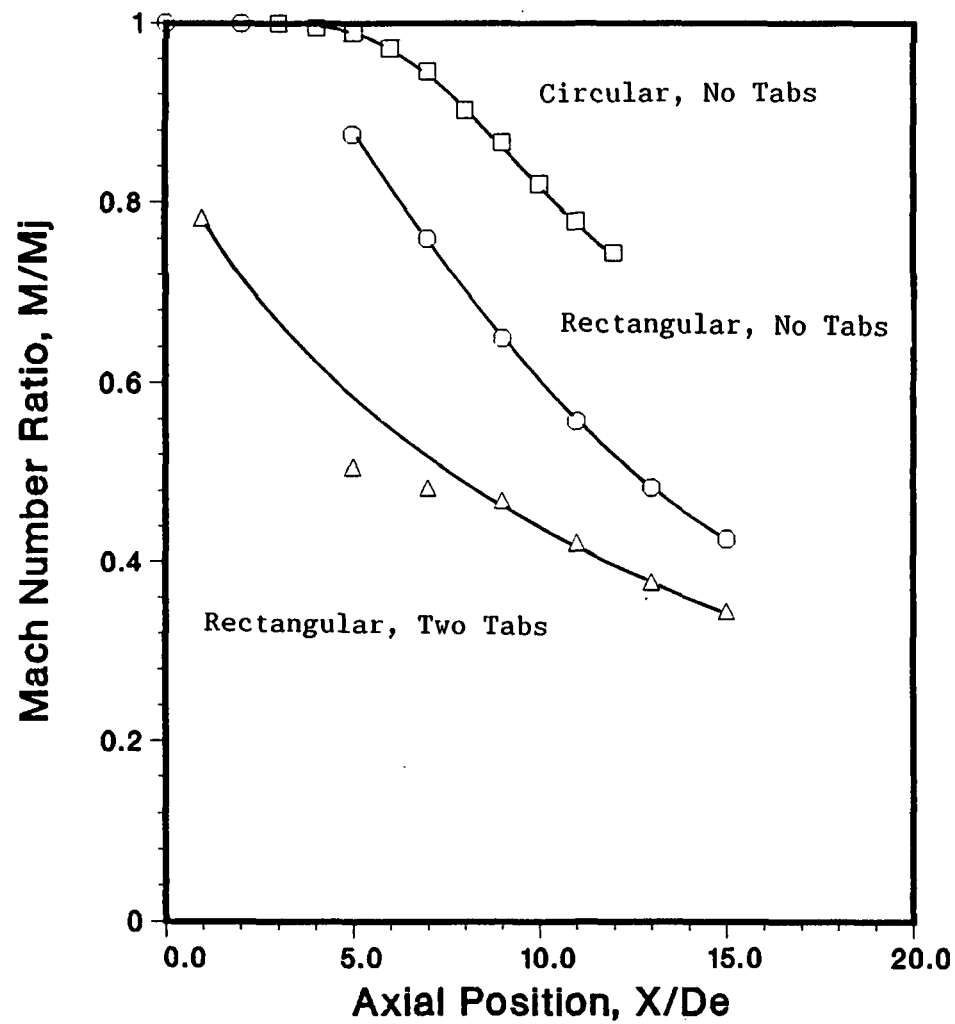


Figure 5.82 Comparison of Axial Decay of Centerline Mach Number for Circular and Rectangular Jets

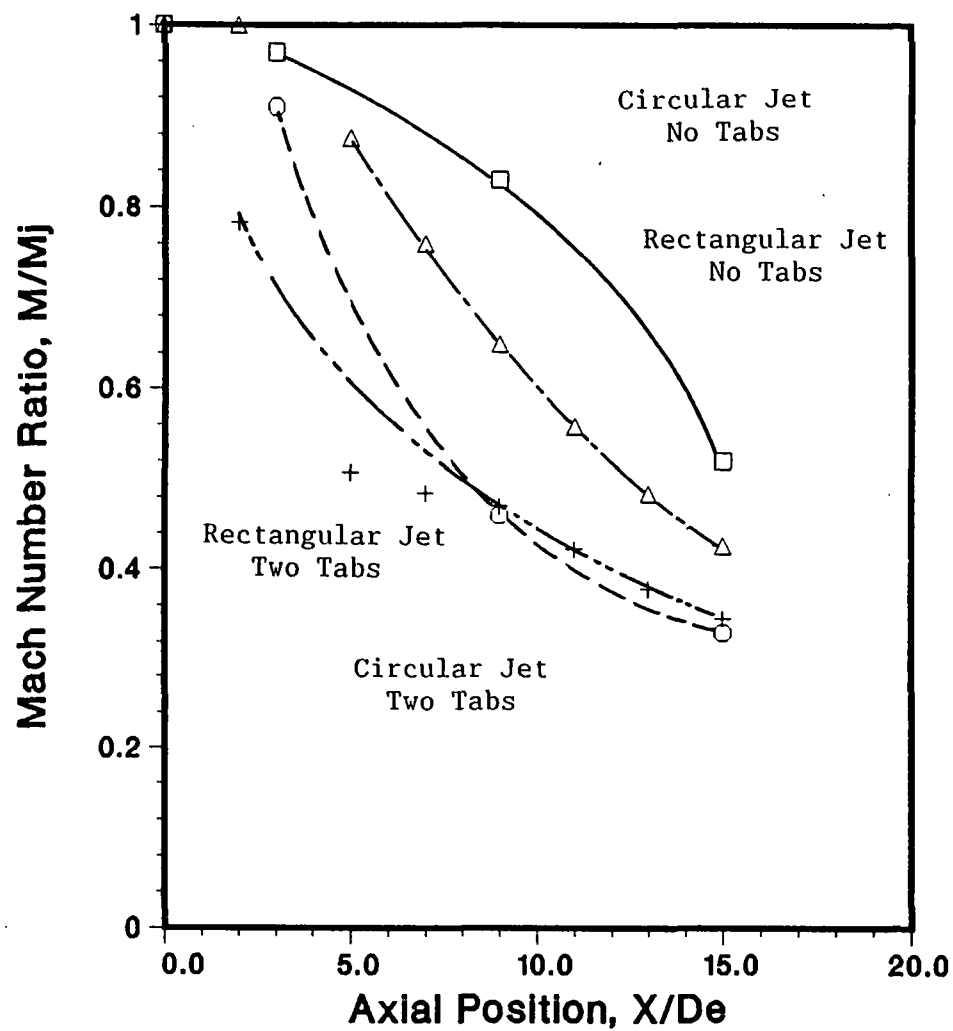


Figure 5.83 Effect of Two Tabs on Axial Decay of Centerline Mach Number for Circular and Rectangular Jets

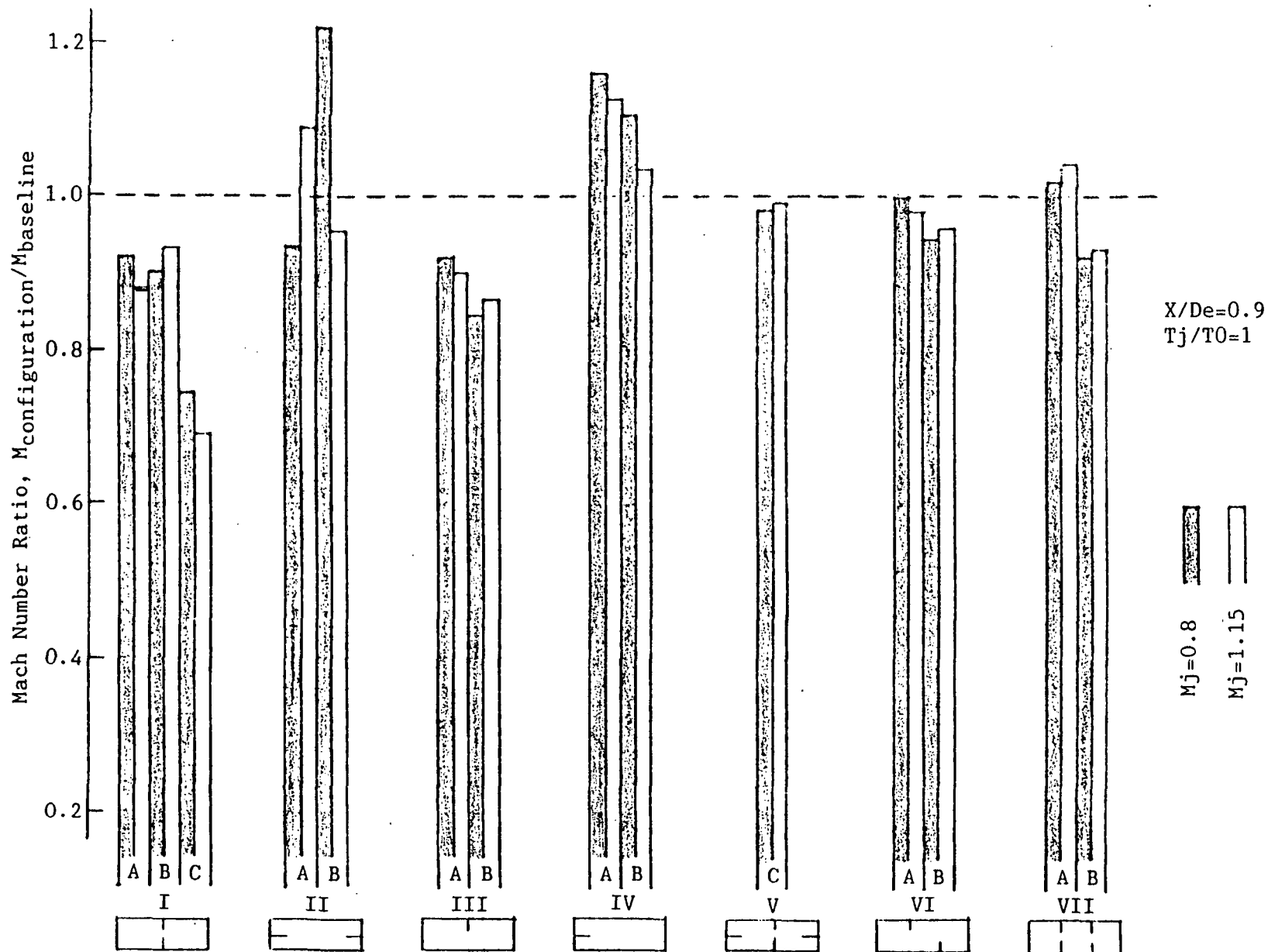


Figure 5.84 Peak Mach Number Ratio to Baseline Mach Number

6.0 CONCLUDING REMARKS

The following general conclusions were obtained from this study:

- 1) Intrusive probes can produce significant errors in the measurements of the jet velocity if the probes are large in diameter and penetrate beyond the jet center.
- 2) Rectangular jets without tabs, compared to circular jets of the same exit area, provide faster jet mixing.
- 3) Further mixing enhancement is possible by using mechanical tabs.

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APPENDIX A

LIST OF SYMBOLS

LIST OF SYMBOLS

<u>Symbol</u>	<u>Meaning</u>
A, B, C	Tab size indicators
A	Nozzle exit area
d	Diagonal distance across rectangular nozzle
d _p	Tab depth
D	Diameter of round nozzles
D _e	Equivalent diameter = $(4A/\pi)^{0.5}$
h	Height (smaller dimension) of rectangular nozzle
K	Degrees Kelvin
M	Mach number (fully expanded for supersonic)
P	Nozzle exit perimeter
Re	Reynolds number based on D, D _e , w, or h
T	Temperature
U	Velocity
w	Width (larger dimension) of rectangular nozzle
w _p	Tab width
X	Streamwise coordinate
Y	Horizontal coordinate
Z	Vertical coordinate
γ	Ratio of specific heats

Subscripts

A, 0	Ambient
D _e	Equivalent diameter
h	Height of rectangular nozzle
J	Jet exit conditions
S	Static
T	Total
w	Width of rectangular nozzle

APPENDIX B

DATA PLOTS

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B-1.0 DATA ORGANIZATION

The data in this appendix are arranged in groupings that reflect the use of the data. This arrangement facilitates comparisons of data by directly providing plots showing an altered profile and the corresponding baseline profile and by placing in the same group those profiles that are most likely to be compared. For added convenience, some profiles, such as baselines, appear in more than one of the major groupings.

B-1.1 Baseline Plots

Velocity and temperature plots for the rectangular nozzle with no tabs installed are referred to as baseline plots. There are three (3) sets in this group---unheated subsonic, unheated supersonic, and heated subsonic. The data sheets (called "file name" on the listings of Volume II) are given in Figure B.1.

B-1.2 Mixing Modification for Unheated Subsonic Jets

The plots in this section show the effect of various tab configurations, including tab sizes, on the velocity profiles for the unheated supersonic jet. These profiles show the modified profile or profiles along with the corresponding baseline profile. Figure B.2 lists the data that is presented in this section.

B-1.3 Mixing Modification for Unheated Supersonic Jets

This section contains data for the unheated supersonic jet for essentially the same configurations as the previous section. The data presented here are identified in Figure B.3.

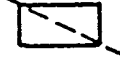
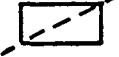
				HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
CONFIGURATION	X/D _E	T _j /T _o	M _j				
0 - 0 (BASELINE)	15	1	0.8	TAB282T	TAB281T	TAB287T	- - - -
	13	1	0.8	TAB302T	TAB293T	TAB145T	- - - -
	11	1	0.8	TAB134T	TAB133T	TAB143T	- - - -
	9	1	0.8	TAB147T	TAB146T	TAB165T	- - - -
	7	1	0.8	TAB130T	TAB129T	TAB144T	- - - -
	5	1	0.8	TAB128T	TAB127T	TAB329T	- - - -
	2	1	0.8	TAB126T	TAB125T	TAB137T	- - - -
	1	1	0.8	- - - -	TAB135T	TAB136T	- - - -
	5	2.3	0.8	TAB337T	TAB338T	TAB343T	- - - -
	7	2.3	0.8	TAB350T	TAB349T	- - - -	- - - -
	9	2.3	0.8	TAB332T	TAB331T	TAB346T	- - - -
	13	2.3	0.8	TAB356T	TAB355T	- - - -	- - - -
	9	1	1.15	TAB185T	TAB203T	- - - -	- - - -

Figure B.1 Baseline Plots

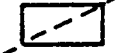
CONFIGURATION	X/D _E	T _j /T _o	M _j	HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
							
0 - 0							
(BASELINE)	9	1	0.8	TAB147T	TAB146T	TAB165T	TAB175T
I - A 	9	1	0.8	TAB157T	TAB158T	TAB168T	TAB176T
I - B	9	1	0.8	TAB149T	TAB148T	TAB167T	TAB180T
III - A 	9	1	0.8	TAB161T	TAB162T	TAB169T	TAB177T
III - B	9	1	0.8	TAB155T	TAB156T	TAB170T	TAB181T
II - A 	9	1	0.8	TAB151T	TAB152T	TAB171T	TAB178T
II - B	9	1	0.8	TAB159T	TAB160T	TAB173T	TAB182T
IV - A 	9	1	0.8	TAB153T	TAB154T	TAB172T	TAB179T
IV - B	9	1	0.8	TAB163T	TAB164T	TAB174T	TAB183T
VI - A 	9	1	0.8	TAB242T	TAB241T	TAB257T	TAB269T
VI - B	9	1	0.8	TAB252T	TAB253T	TAB264T	TAB273T
VII - A 	9	1	0.8	TAB239T	TAB240T	TAB256T	TAB268T
VII - B	9	1	0.8	TAB248T	TAB249T	TAB261T	TAB272T
V - C 	9	1	0.8	TAB275T	TAB276T	TAB260T	TAB274T
I - C 	9	1	0.8	TAB365T	TAB364T	- - - -	- - - -

Figure B.2 Mixing Modification for Unheated Subsonic Jets

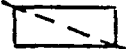
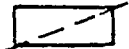
				HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
CONFIGURATION	X/D _E	T _j /T _o	M _j				
0 - 0 (BASELINE)	9	1	1.15	TAB185T	TAB203T	TAB209T	TAB221T
I - A 	9	1	1.15	TAB187T	TAB204T	TAB210T	TAB223T
I - B	9	1	1.15	TAB196T	TAB203T	TAB213T	TAB226T
III - A 	9	1	1.15	TAB189T	TAB205T	TAB215T	TAB224T
III - B	9	1	1.15	TAB198T	TAB197T	TAB214T	TAB227T
II - A 	9	1	1.15	TAB191T	TAB206T	TAB220T	TAB228T
II - B	9	1	1.15	TAB200T	TAB199T	TAB219T	TAB231T
IV - A 	9	1	1.15	TAB193T	TAB207T	TAB217T	TAB230T
IV - B	9	1	1.15	TAB202T	TAB201T	TAB218T	TAB232T
VI - A 	9	1	1.15	TAB243T	TAB244T	TAB258T	TAB234T
VI - B	9	1	1.15	TAB251T	TAB250T	TAB263T	TAB236T
VII - A 	9	1	1.15	TAB238T	TAB237T	TAB255T	TAB233T
VII - B	9	1	1.15	TAB248T	TAB249T	TAB262T	TAB235T
V - C 	9	1	1.15	TAB278T	TAB277T	TAB259T	TAB266T

Figure B.3 Mixing Modification for Unheated Supersonic Jets

B-1.4 Effect of Axial Distance on Mixing Modification

The plots in this section illustrate the development of mixing modification by selected configurations as a function of X/D_e location. The data sets are listed in Figure B.4.

B-1.5 Mixing Modification for Heated Subsonic Heats

This section compares the modification of jet velocity and temperature profiles by certain tab configurations with a heated subsonic jet. Again, the modified profiles are compared with the corresponding baseline profiles. Figure B.5 lists the data sets used here.

B-1.6 Miscellaneous

This section contains miscellaneous plots such as those made with the round two-inch and four-inch diameter nozzles. Figure B.6 lists the test configurations and data sets of this section.

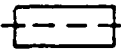
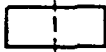
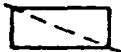
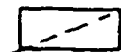
				HORIZONTAL	VERTICAL	DIAGONAL -14°	DIAGONAL +14°
CONFIGURATION	X/D _E	T _j /T ₀	M _j				
I - B 	15	1	0.8	TAB283T	TAB284T	TAB290T	- - - -
	13	1	0.8	TAB295T	TAB294T	TAB291T	- - - -
	11	1	0.8	TAB298T	TAB299T	TAB305T	- - - -
	9	1	0.8	TAB149T	TAB148T	TAB167T	TAB180T
	7	1	0.8	TAB324T	TAB325T	TAB306T	- - - -
	5	1	0.8	TAB321T	TAB320T	TAB308T	- - - -
	2	1	0.8	TAB316T	TAB317T	TAB313T	- - - -
III - B 	15	1	0.8	TAB286T	TAB285T	TAB289T	- - - -
	13	1	0.8	TAB296T	TAB297T	TAB292T	- - - -
	11	1	0.8	TAB301T	TAB300T	TAB304T	- - - -
	9	1	0.8	TAB155T	TAB156T	TAB170T	TAB181T
	7	1	0.8	TAB327T	TAB326T	TAB307T	- - - -
	5	1	0.8	TAB322T	TAB323T	TAB309T	- - - -
	2	1	0.8	TAB319T	TAB318T	TAB311T	- - - -

Figure B.4 Effect of Axial Distance on Mixing Modification

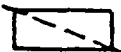
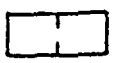
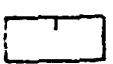
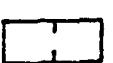
				HORIZONTAL	VERTICAL	DIAGONAL -14°
CONFIGURATION	X/D _E	T _j /T _o	M _j			
0 - 0 (BASELINE)	5	2.3	0.8	TAB337T	TAB338T	TAB343T
	7	2.3	0.8	TAB350T	TAB349T	- - - -
	9	2.3	0.8	TAB332T	TAB331T	TAB346T
	13	2.3	0.8	TAB356T	TAB355T	- - - -
I - B 	5	2.3	0.8	TAB340T	TAB339T	TAB344T
	7	2.3	0.8	TAB351T	TAB352T	- - - -
	9	2.3	0.8	TAB333T	TAB334T	TAB347T
	13	2.3	0.8	TAB354T	TAB353T	- - - -
III - B 	5	2.3	0.8	TAB341T	TAB342T	TAB345T
	9	2.3	0.8	TAB336T	TAB335T	TAB348T
I - C 	9	2.3	0.8	TAB359T	TAB360T	- - - -
	13	2.3	0.8	TAB357T	TAB358T	- - - -

Figure B.5 Mixing Modification for Heated Subsonic Jets

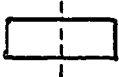
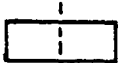
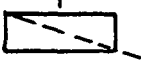
CONFIGURATION	X/D _E	T _j /T _o	M _j	HORIZONTAL		VERTICAL	COMMENTS
							
TWO-INCH ROUND	11	1	0.8	TAB366T	TAB367T	BASELINE	
"	15	1	0.8	TAB369T	TAB368T	BASELINE	
FOUR-INCH PIPE	1	1	0.2	---	TAB058S	BASELINE	
TWO-INCH ROUND	3	1.6	0.8	TAB506T	TAB505S	KIEL PROBE W/ T/C	
"	3	1.6	0.8	TAB504S	---	KIEL PROBE W/O T/C	
"	3	1	0.6	TAB510S	---	BOUNDARY LAYER PROBE	
"	3	1.6	0.8	---	TAB523	KIEL PROBE W/ T/C INVERTED PROFILE FROM ABOVE	
"	3	1.6	0.8	---	TAB508S	BOUNDARY LAYER PROBE	
"	1	1.6	0.8	TAB513T	---	CENTRO PROBE	
"	1	1.6	0.8	TAB515T	---	KIEL PROBE W/ T/C	
0-0 	1	1	0.8	---	TAB049S	NORMAL NOZZLE	
"	1	1	0.8	---	TAB053S	INVERTED NOZZLE & PROFILE	
"	1	1	0.8	---	TAB048S	SKEWED PROFILE	
TWO-INCH ROUND	9	1	0.8	TAB519S	---	KIEL PROBE W/ T/C	
"	9	1	0.8	TAB520S	---	BOUNDARY LAYER PROBE	
0-0 	1	1	0.8	TAB135T	---		
" 	1	1	0.8	TAB136T	---		

Figure B.6 Miscellaneous

B-2.0 NOMENCLATURE

This section presents a description of the tab configurations investigated, the coordinate system, the traverse paths used, and the nomenclature for the figures.

B-2.1 Configurations

The configurations tested are shown in Figure B.7.

B-2.2 Coordinate System and Traverse Paths

The orthogonal coordinate system has its origin at the center of the nozzle exit plane. The X-coordinate is positive in the downstream direction, the Y-coordinate is positive to the left of the jet axis looking downstream, and the Z-coordinate is positive upwards as shown in Figure B.8.

Horizontal traverses were made through the axis of the jet and parallel to the major axis of the rectangular nozzle. Vertical traverses were made similarly but referenced to the minor axis of the nozzle. Diagonal traverses were made in the horizontal direction but with the nozzle rotated clockwise 14° looking downstream for the -14° case, and counterclockwise for the $+14^\circ$ case. These traverses are shown in Figure B.9. For the round nozzles, the traverses were simply horizontal or vertical through the jet axis.

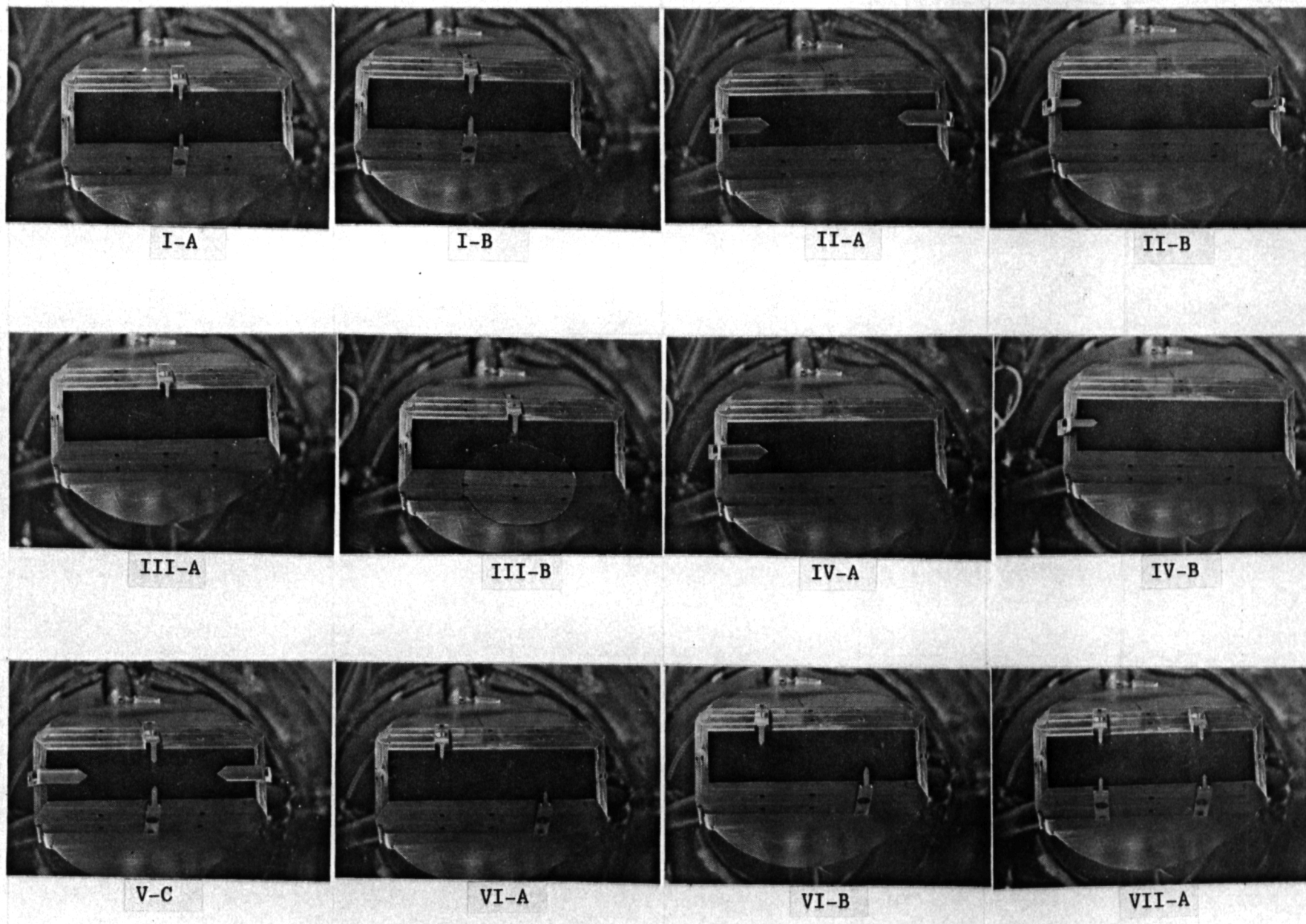


Figure B.7 Tab Configurations

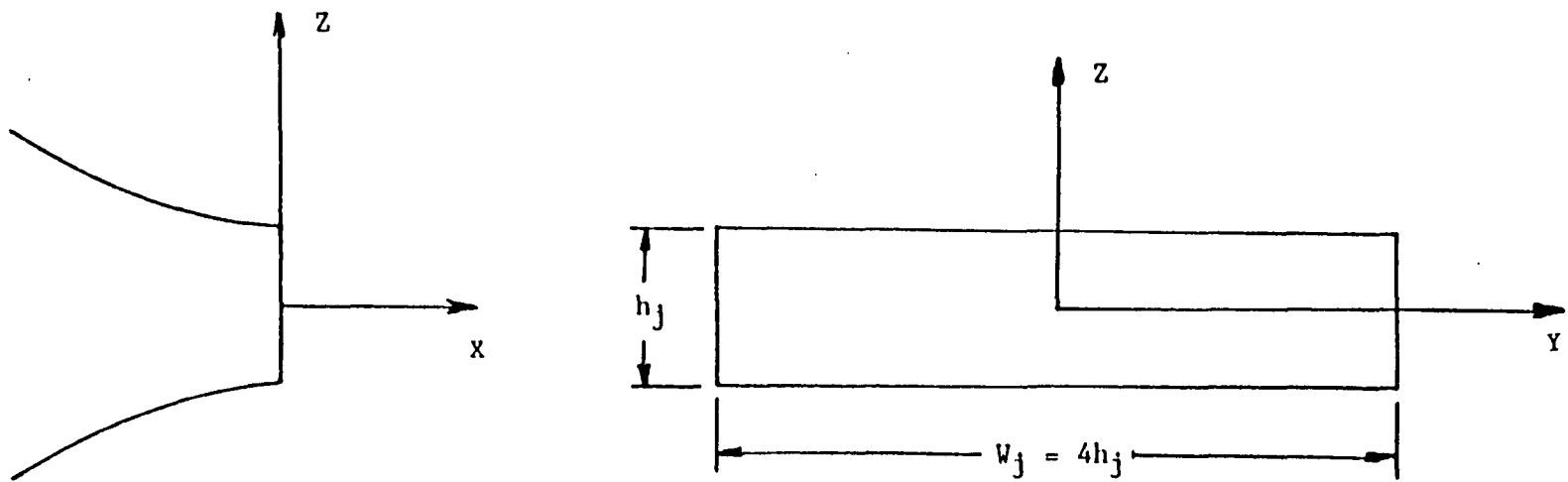


Figure B.8 Coordinate System

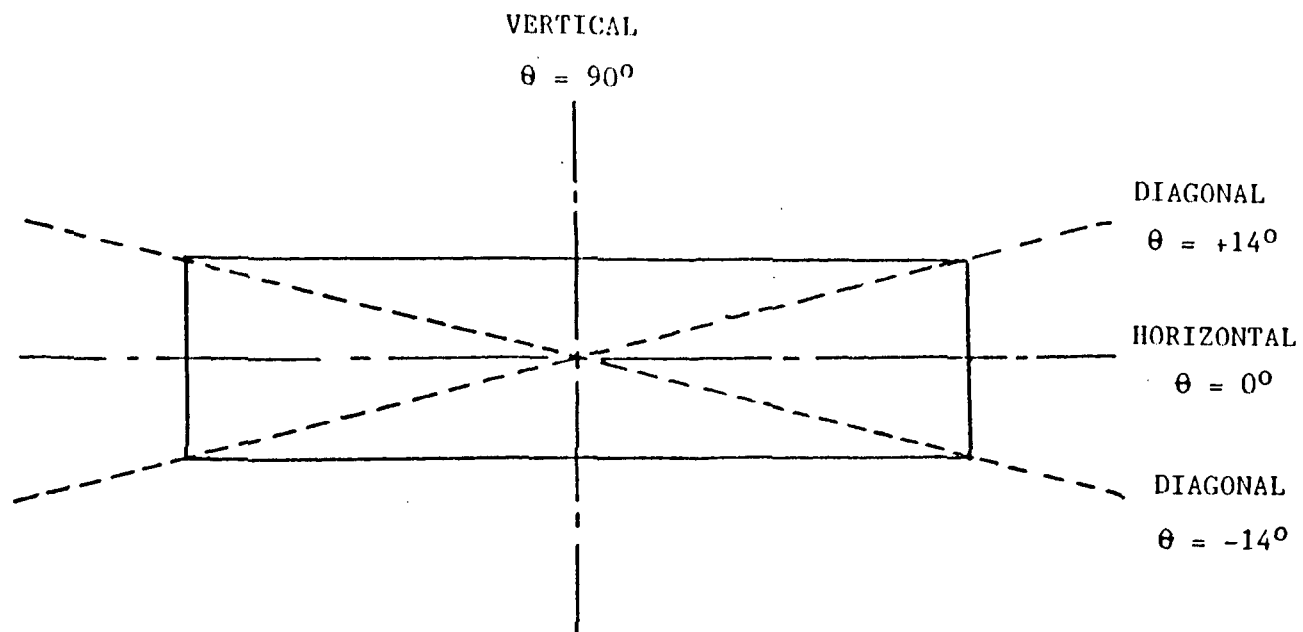


Figure B.9 Traverse Paths

B-2.3 Nomenclature for Figures

The basic nomenclature used in the figures is defined in Appendix A. This subsection presents additional comments to further clarify the definition and use of some of the parameter ratios that appear on the right hand side of the figures. Figure B.10 will be used to define the parameters.

M_j is the fully expanded jet Mach number based on the plenum total pressure and ambient pressure. It includes the effects of variable specific heat ratio.

T_{TJ} and T_A are plenum total temperature and ambient temperature, respectively.

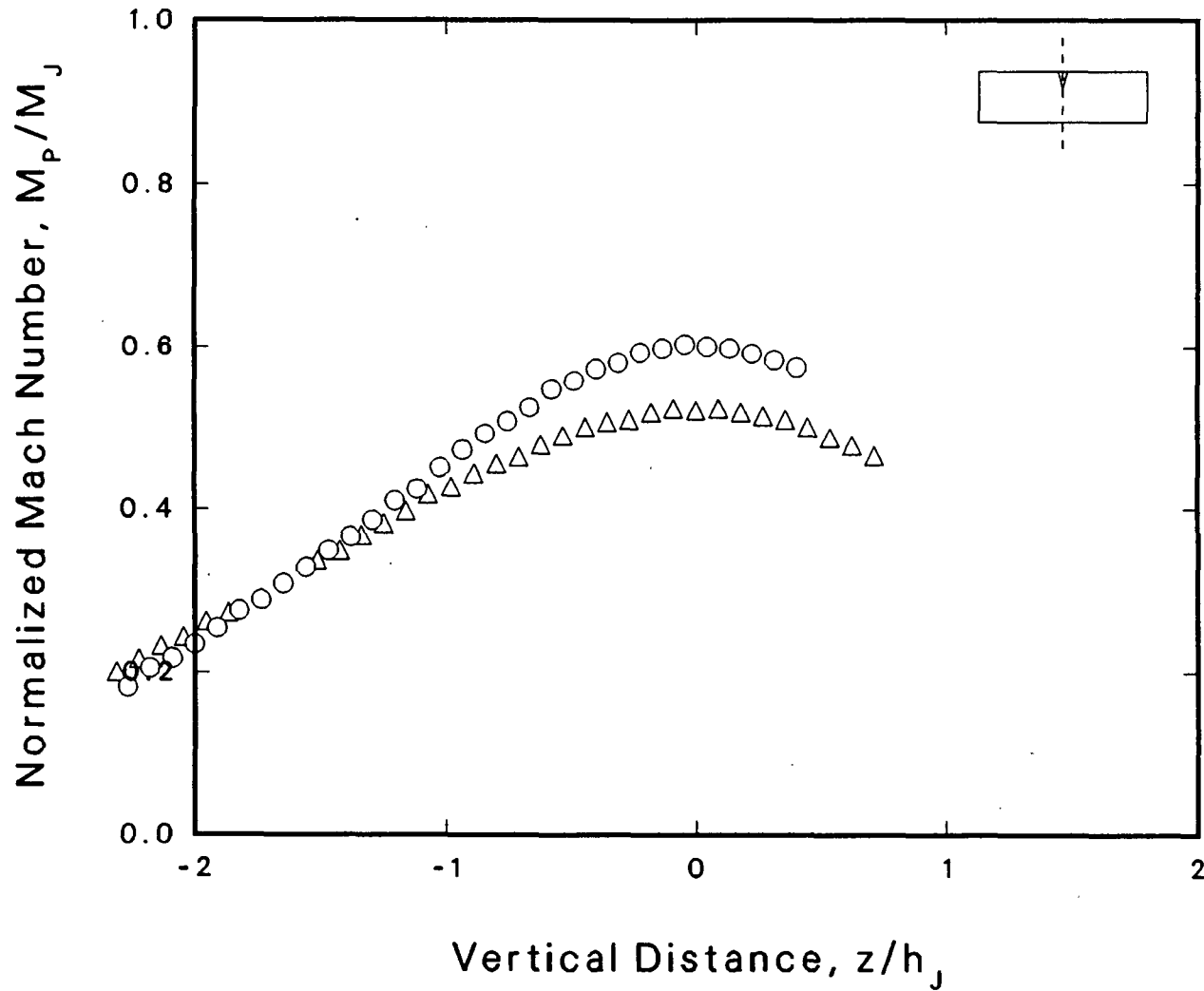
U_j is the velocity corresponding to M_j .

The Reynolds numbers are derived from conditions in the fully expanded jet and are based on equivalent jet diameter (De_j), nozzle height or minor axis length (h), and nozzle width or major axis length (w) as indicated by the subscript.

P_A is the ambient pressure.

X/De_j is the X location of the measurement plane in terms of jet equivalent diameters. X is positive measured downstream from the nozzle exit.

Z/h_j is the vertical offset of a horizontal or diagonal profile. If Z/h_j is zero, the traverse was made through the center of the baseline jet. If it is non-zero, the jet was not centered and the traverse was made at the indicated height in order to pass through the center of the baseline jet on the Z axis. Z is positive above the center of the nozzle exit.



Sym	O	Δ
File	TAB331T	TAB335T
Config	0-0	III-B
M_j	0.802	0.801
T_{TJ}/T_A	2.29	2.27
T_{TJ}, K	621.9	616.3
U_j, mps	375.9	373.9
Re_{D_o}	0.411	0.419
Re_h	0.182	0.185
Re_w	0.727	0.741
p_A, kPa	98.002	98.849
T_A, K	272.0	271.5
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	-6.0

Figure B.10 Sample for Nomenclature Definition
Config. III, Vertical Mach Number Profile

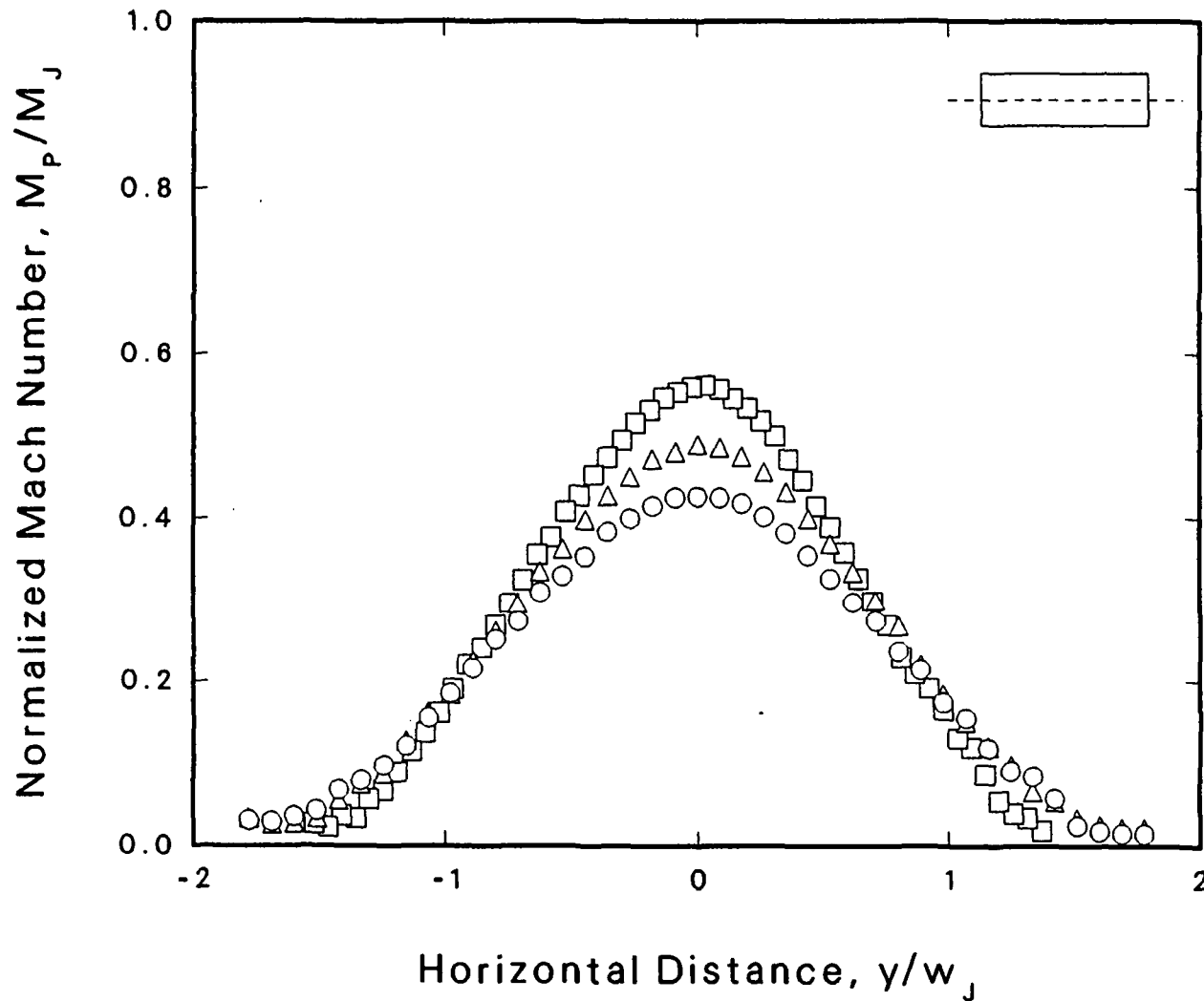
Y/w_j is the horizontal offset of a vertical profile. Y is positive to the right of the nozzle center as viewed from downstream. If Y/w_j is non-zero, the jet was not centered and the traverse was made at the indicated value in order to pass through the center of the baseline jet on the Y axis.

ΔY is the horizontal offset required to center the peak of a horizontal or diagonal profile; ΔZ is the vertical offset required to center a vertical profile. These offsets are used only to center the plots and do not change in any way the tabulated as-run values as given in Volume II. The plots are centered to facilitate the comparison of peak levels and profile shapes.

B-3.0

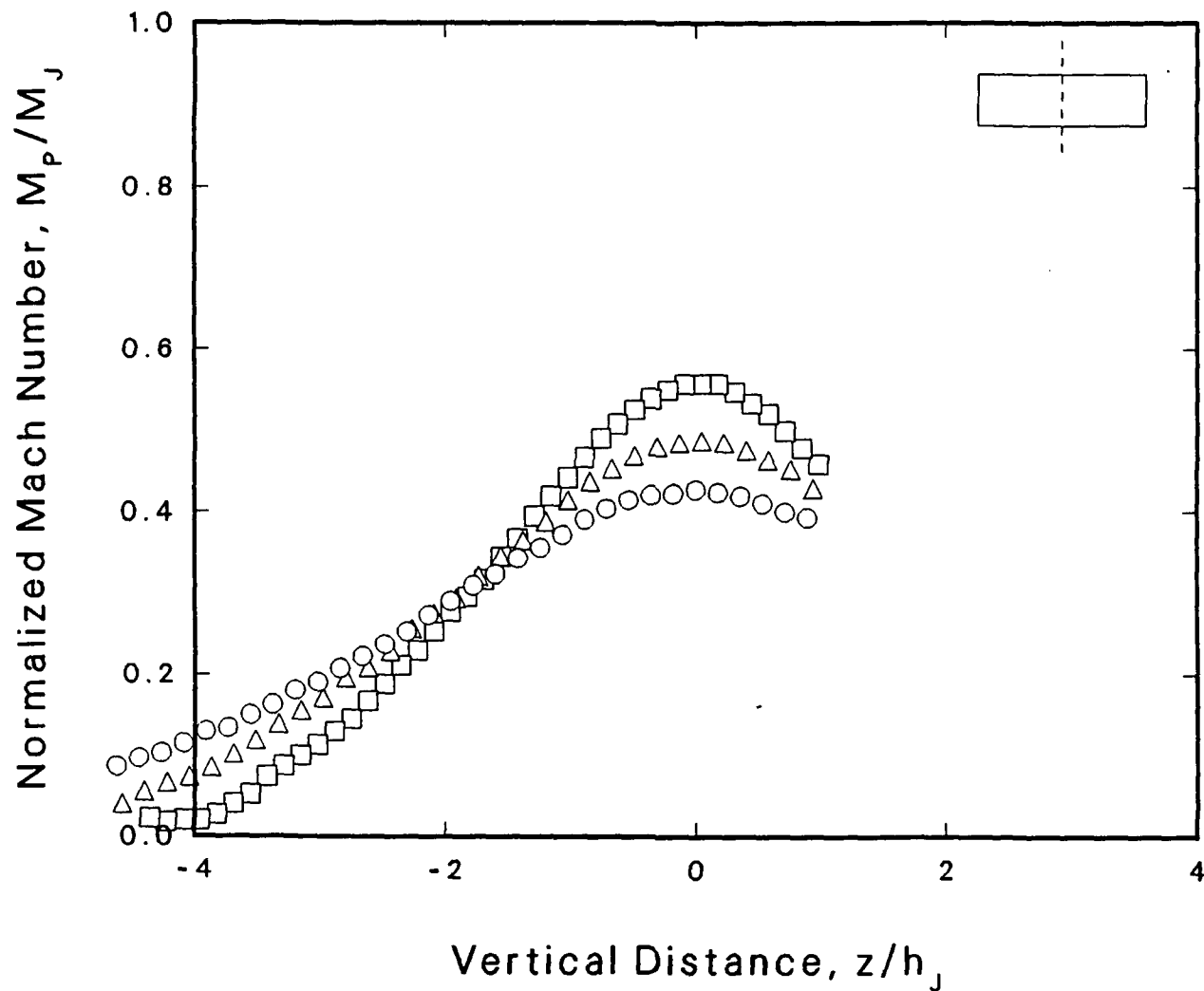
DATA PLOTS

B-3.1 Baseline Rectangular Nozzle Characteristics



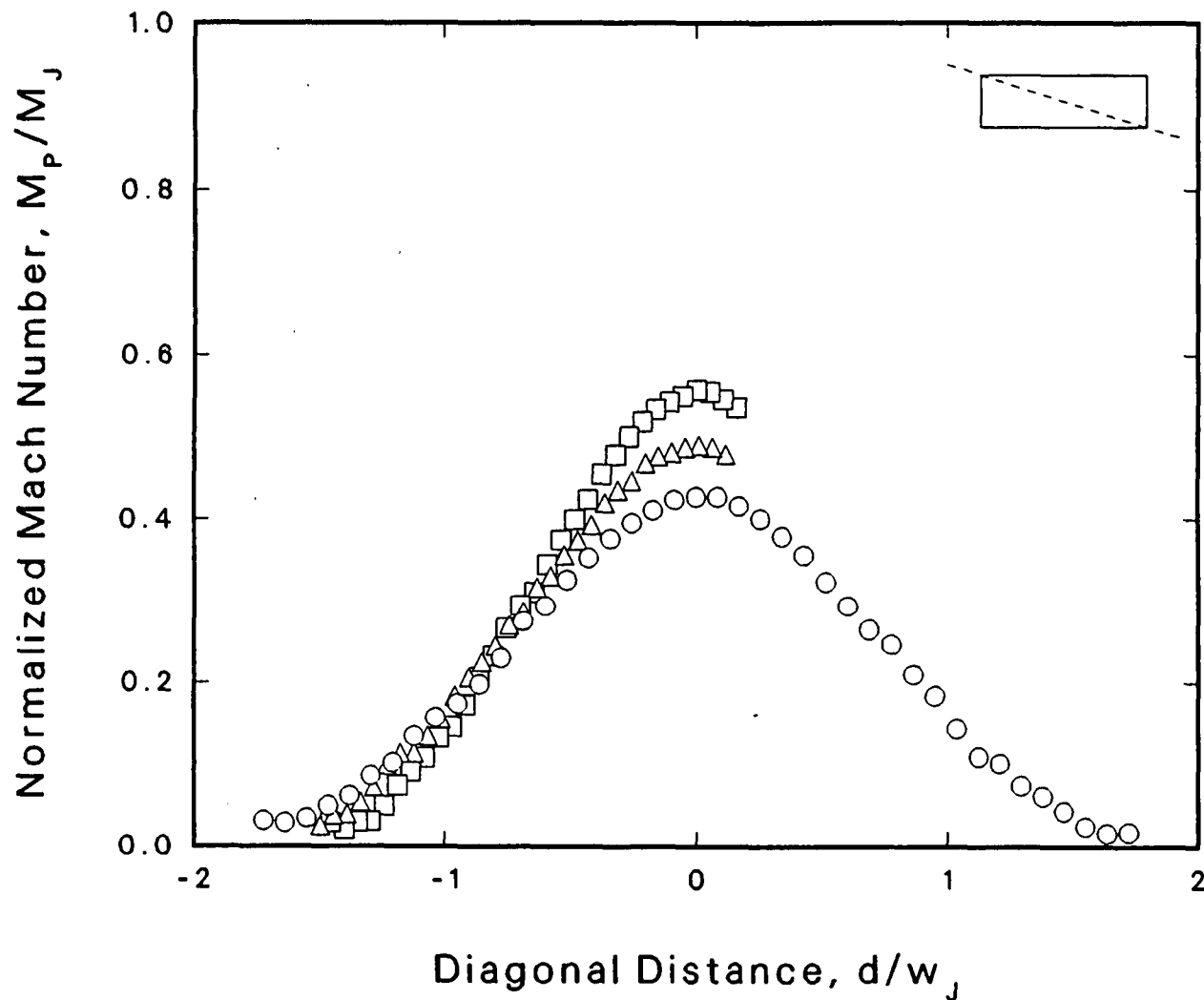
Sym	○	△	□
File	TAB282T	TAB302T	TAB134T
Config	0-0	0-0	0-0
M_J	0.798	0.798	0.802
T_{TJ}/T_A	0.97	0.98	0.98
T_{TJ}, K	280.6	282.2	286.8
U_J, mps	252.6	253.2	256.5
Re_{De}	1.110	1.100	1.085
Re_h	0.492	0.487	0.481
Re_w	1.965	1.948	1.920
p_A, kPa	98.442	98.307	98.375
T_A, K	289.8	289.4	293.7
De_J, mm	50.8	50.8	50.8
X/De_J	15.00	13.00	11.00
Z/h_J	0.00	0.00	-0.09
$\Delta Y, mm$	0.0	0.0	7.0

Figure B.11 Baseline Horizontal Mach Number Profile,
 $X/De=15,13,11$, $M_J=0.8$, $T_J/T_0=1$



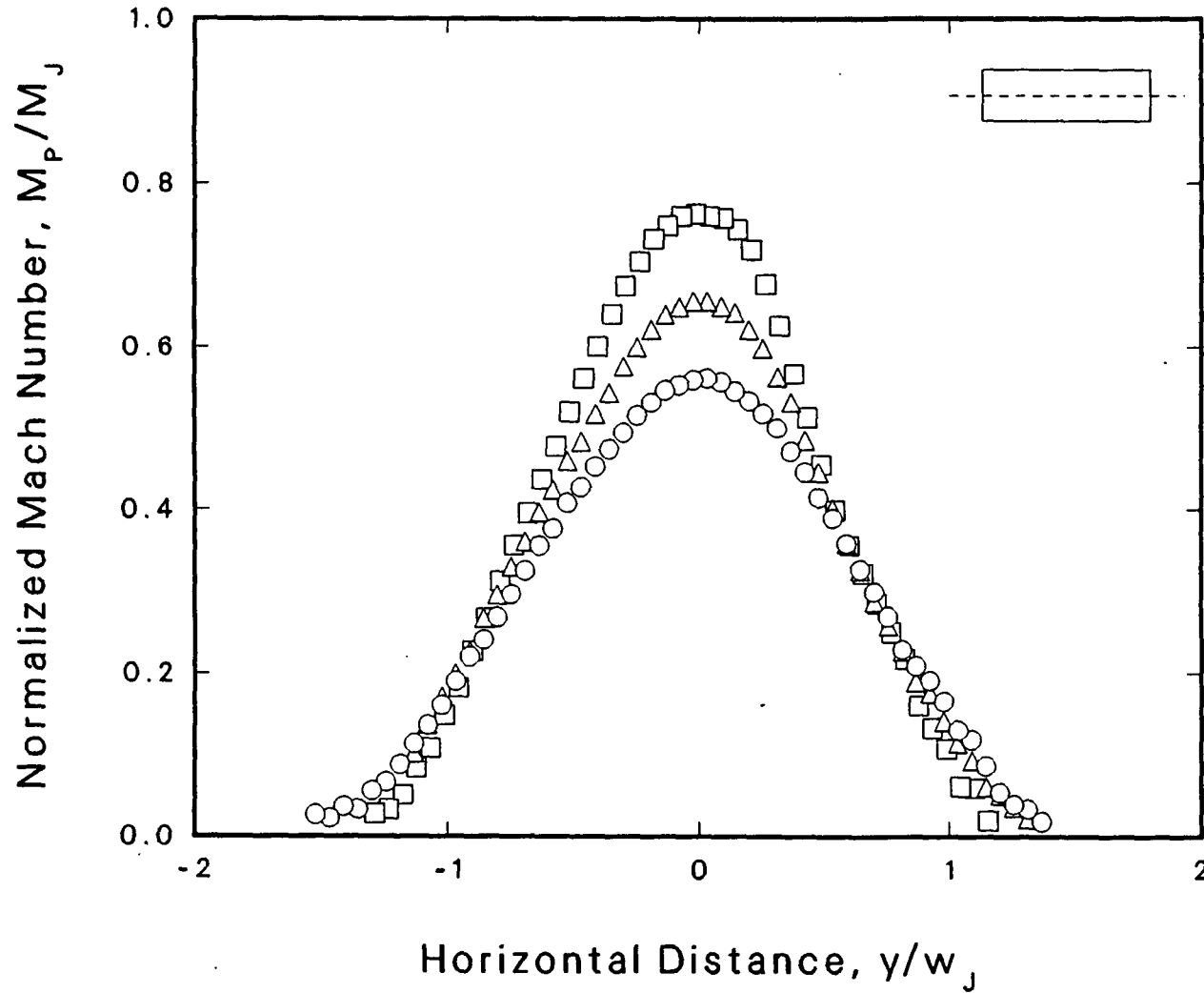
Sym	○	△	□
File	TAB281T	TAB293T	TAB133T
Config	0-0	0-0	0-0
M_j	0.798	0.798	0.798
T_{TJ}/T_A	0.97	0.96	0.98
T_{TJ}, K	281.3	281.9	286.9
U_j, mps	252.9	253.1	255.3
Re_{De}	1.107	1.095	1.078
Re_h	0.490	0.485	0.477
Re_w	1.959	1.939	1.908
p_A, kPa	98.476	97.731	98.408
T_A, K	290.9	293.2	293.6
De_j, mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Y/w_j	0.00	0.00	0.08
$\Delta Z, mm$	0.0	-1.0	-2.0

Figure B.12 Baseline Vertical Mach Number Profile,
 $X/D_e=15,13,11$, $M_j=0.8$, $T_j/T_0=1$



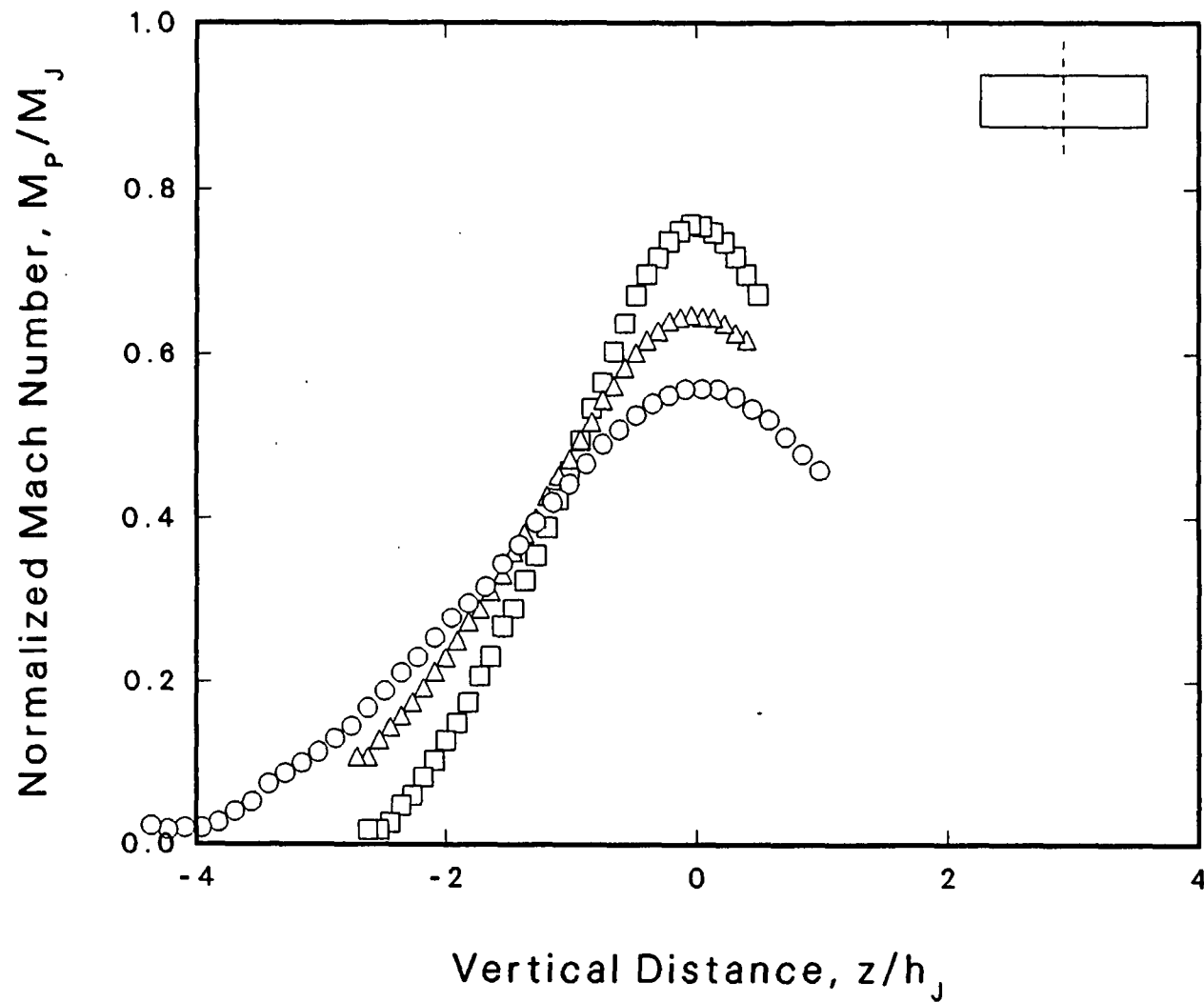
Sym	○	Δ	□
File	TAB287T	TAB145T	TAB143T
Config	0-0	0-0	0-0
M_j	0.797	0.802	0.797
T_{TJ}/T_A	0.98	0.99	1.00
T_{TJ} , K	280.4	285.7	285.1
U_j , mps	252.2	256.0	254.3
Re_{De}	1.109	1.071	1.074
Re_h	0.491	0.474	0.476
Re_w	2.024	1.955	1.960
p_A , kPa	98.442	96.648	97.359
T_A , K	286.7	289.5	285.7
De_j , mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Z/h_j	0.00	0.44	0.00
ΔY , mm	0.0	9.0	6.0

Figure B.13 Baseline Diagonal Mach Number Profile,
 $X/De=15,13,11$, $M_j=0.8$, $T_j/T_0=1$



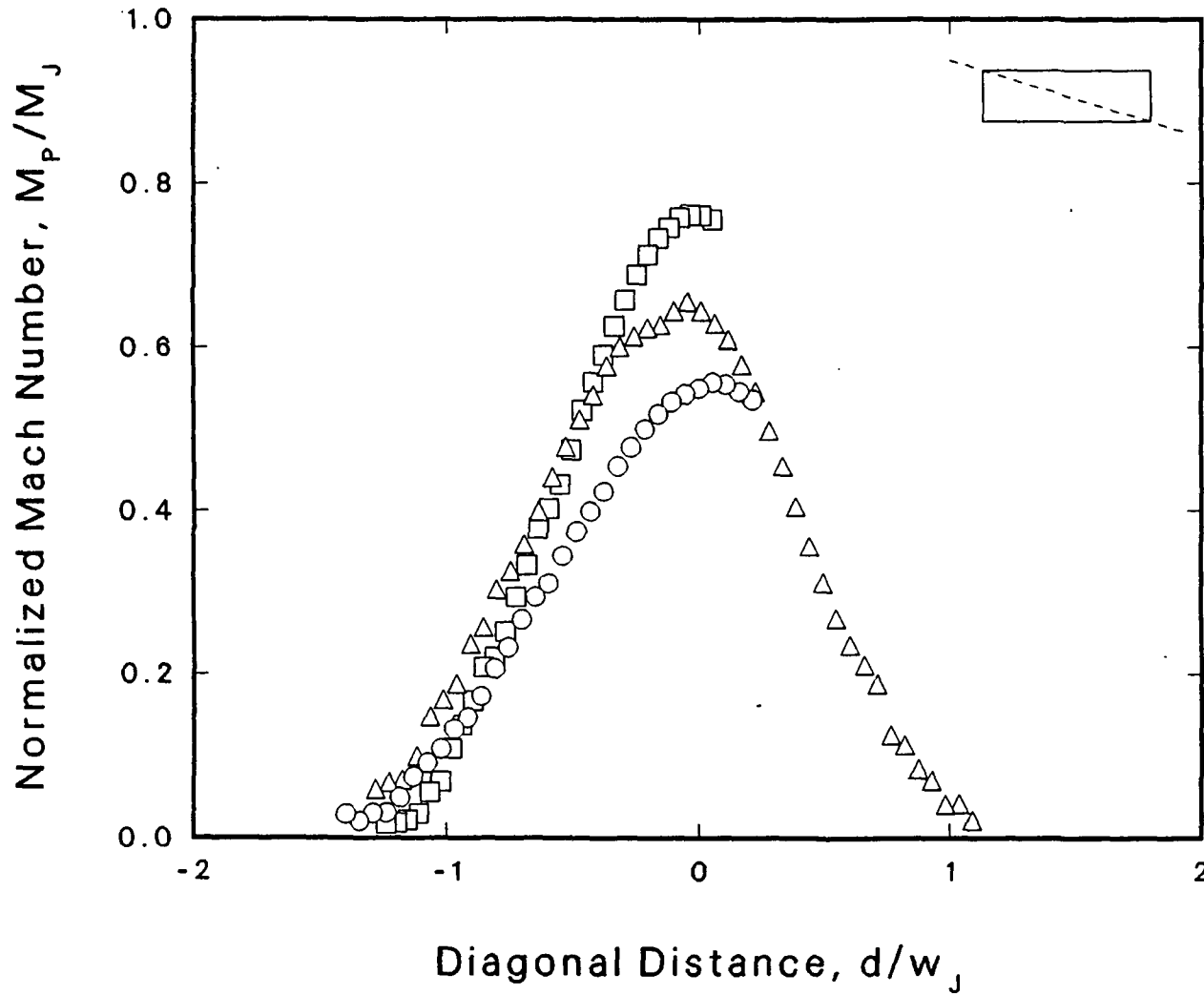
Sym	○	△	□
File	TAB134T	TAB147T	TAB130T
Config	0-0	0-0	0-0
M_j	0.802	0.800	0.797
T_{TJ}/T_A	0.98	0.97	0.97
T_{TJ} , K	286.8	285.6	287.2
U_j , mps	256.5	255.2	255.2
Re_{D_e}	1.085	1.087	1.072
Re_h	0.481	0.482	0.475
Re_w	1.920	1.926	1.898
p_A , kPa	98.375	98.375	98.171
T_A , K	293.7	294.6	294.6
De_j , mm	50.8	50.8	50.8
X/De_j	11.00	9.00	7.00
Z/h_j	-0.09	0.00	-0.04
ΔY , mm	7.0	-8.0	6.0

Figure B.14 Baseline Horizontal Mach Number Profile,
 $X/D_e=11,9,7$, $M_j=0.8$, $T_j/T_0=1$



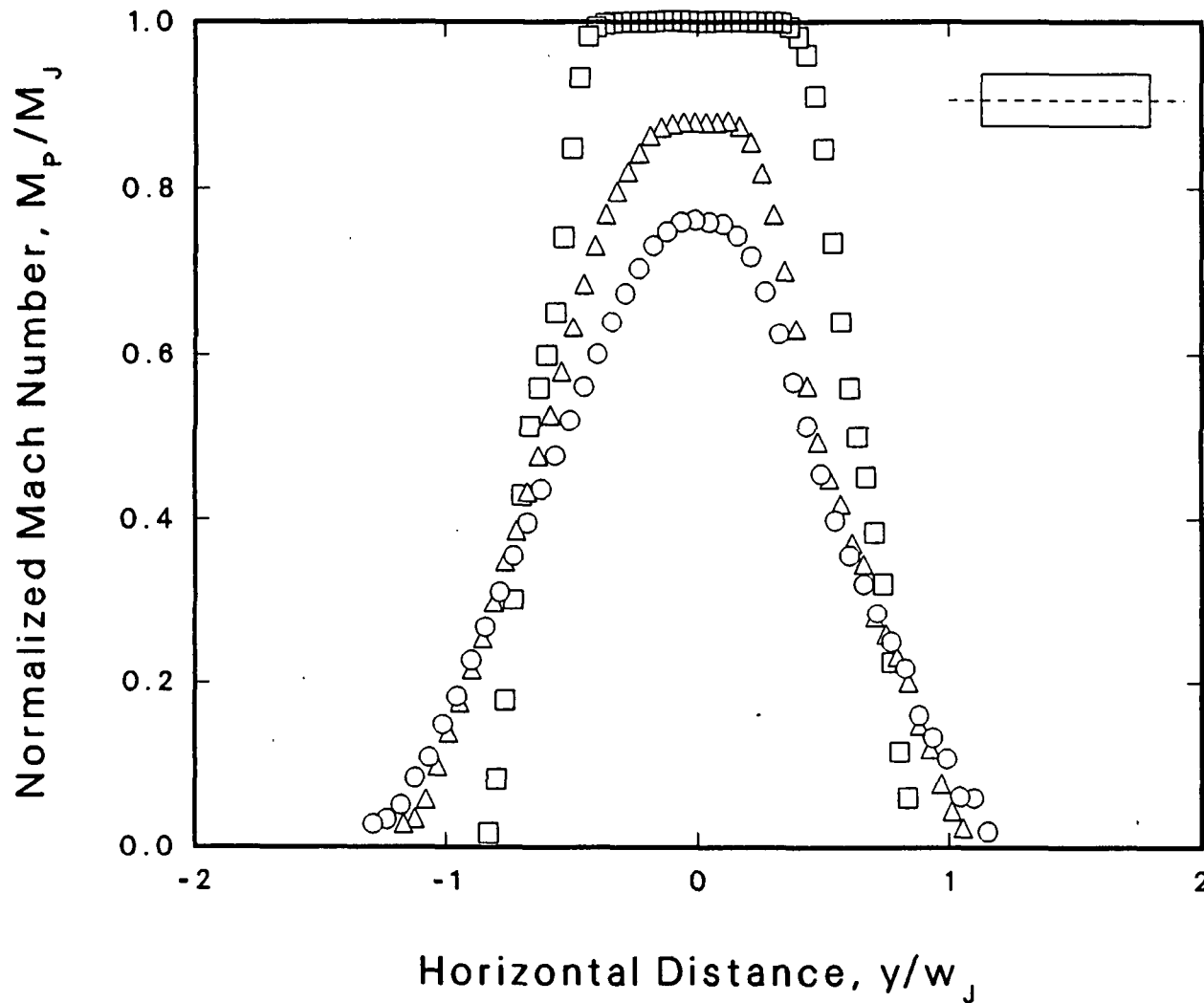
Sym	○	△	□
File	TAB133T	TAB146T	TAB129T
Config	0-0	0-0	0-0
M_j	0.798	0.800	0.798
T_{Tj}/T_A	0.98	0.97	0.98
T_{Tj} , K	286.9	285.8	286.6
U_j , mps	255.3	255.4	255.3
Re_{De}	1.078	1.086	1.079
Re_h	0.477	0.481	0.478
Re_w	1.908	1.922	1.910
p_A , kPa	98.408	98.375	98.307
T_A , K	293.6	294.9	291.8
De_j , mm	50.8	50.8	50.8
X/De_j	11.00	9.00	7.00
Y/w_j	0.08	0.00	0.00
ΔZ , mm	-2.0	1.0	-1.0

Figure B.15 Baseline Vertical Mach Number Profile,
 $X/D_e=11,9,7$, $M_j=0.8$, $T_j/T_0=1$



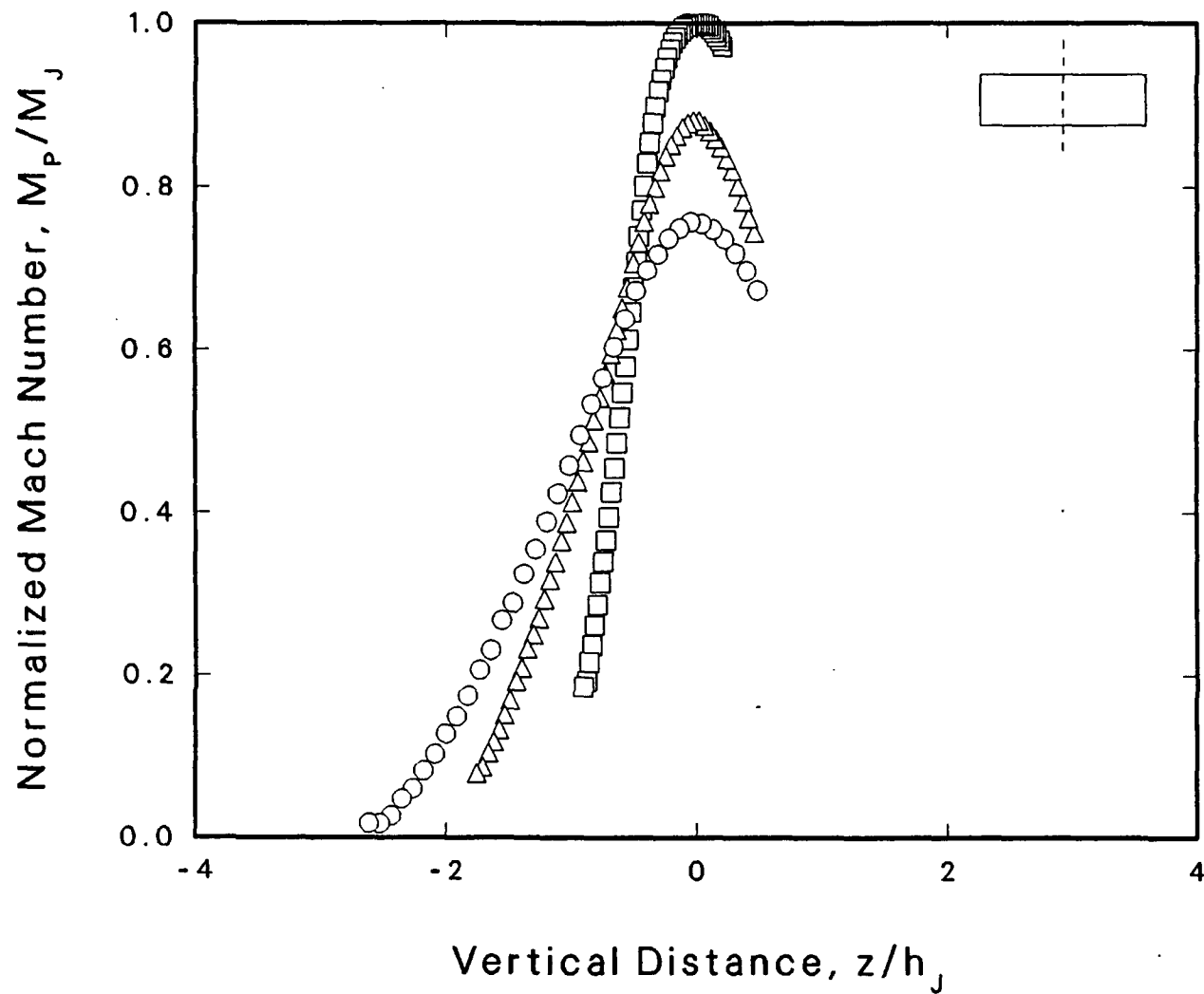
Sym	○	△	□
File	TAB143T	TAB165T	TAB144T
Config	0-0	0-0	0-0
M_j	0.797	0.797	0.799
T_{TJ}/T_A	1.00	0.98	0.99
T_{TJ}, K	285.1	285.1	285.4
U_j, mps	254.3	254.3	254.9
Re_{De}	1.074	1.088	1.073
Re_h	0.476	0.482	0.475
Re_w	1.960	1.985	1.957
p_A, kPa	97.359	98.713	97.223
T_A, K	285.7	290.6	288.3
De_j, mm	50.8	50.8	50.8
X/De_j	11.00	9.00	7.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	9.0	5.0

Figure B.16 Baseline Diagonal Mach Number Profile,
 $X/De=11,9,7$, $M_j=0.8$, $T_j/T_0=1$



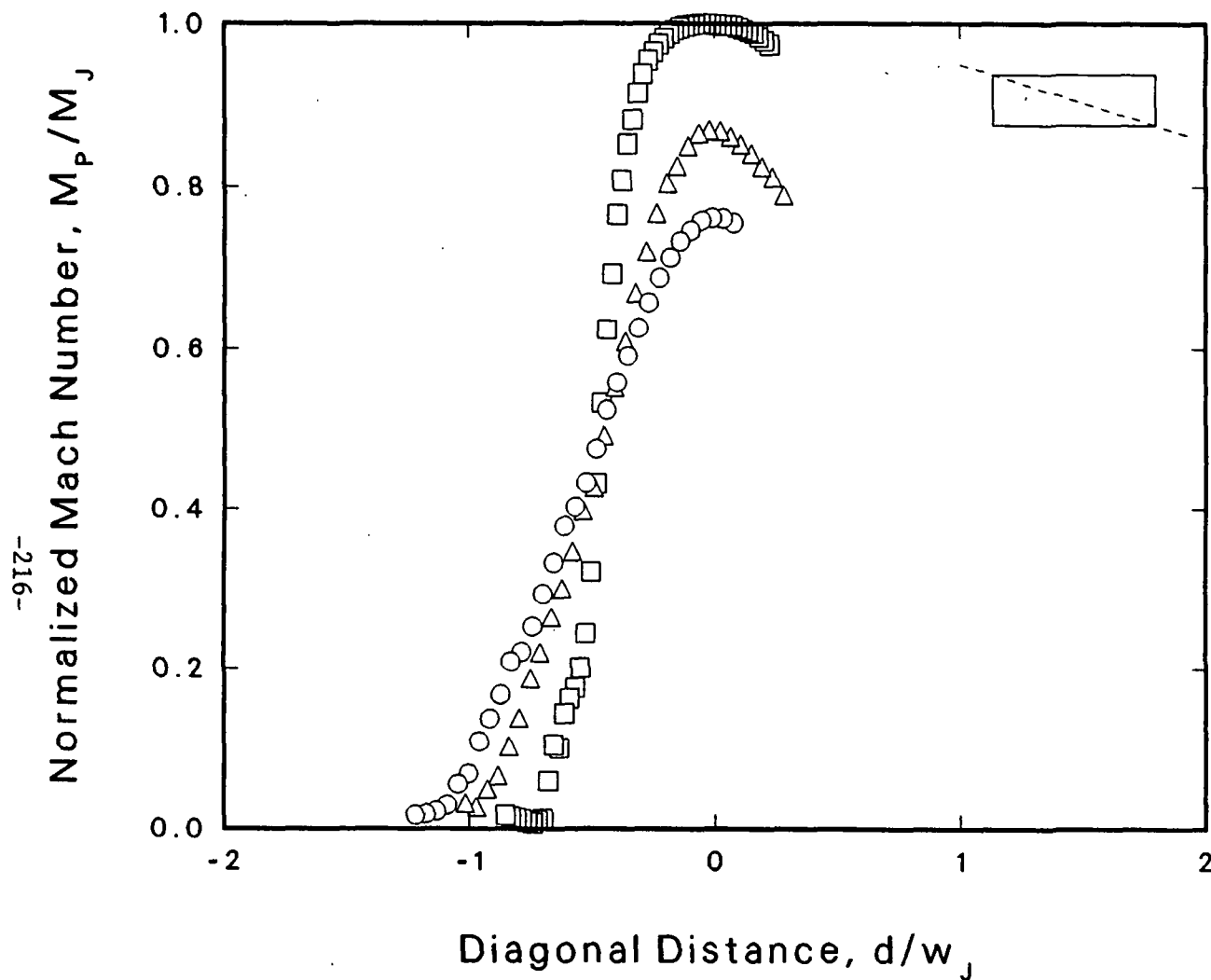
Sym	○	Δ	□
File	TAB130T	TAB128T	TAB126T
Config	0-0	0-0	0-0
M_j	0.797	0.796	0.798
T_{Tj}/T_A	0.97	1.00	1.01
T_{Tj} , K	287.2	285.3	285.3
U_j , mps	255.2	253.9	254.5
Re_{De}	1.072	1.081	1.083
Re_h	0.475	0.479	0.480
Re_w	1.898	1.913	1.917
p_A , kPa	98.171	98.341	98.205
T_A , K	294.6	284.2	283.1
De_j , mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Z/h_j	-0.04	-0.02	0.02
ΔY , mm	6.0	5.0	0.0

Figure B.17 Baseline Horizontal Mach Number Profile,
 $X/D_e=7,5,2$, $M_j=0.8$, $T_j/T_0=1$



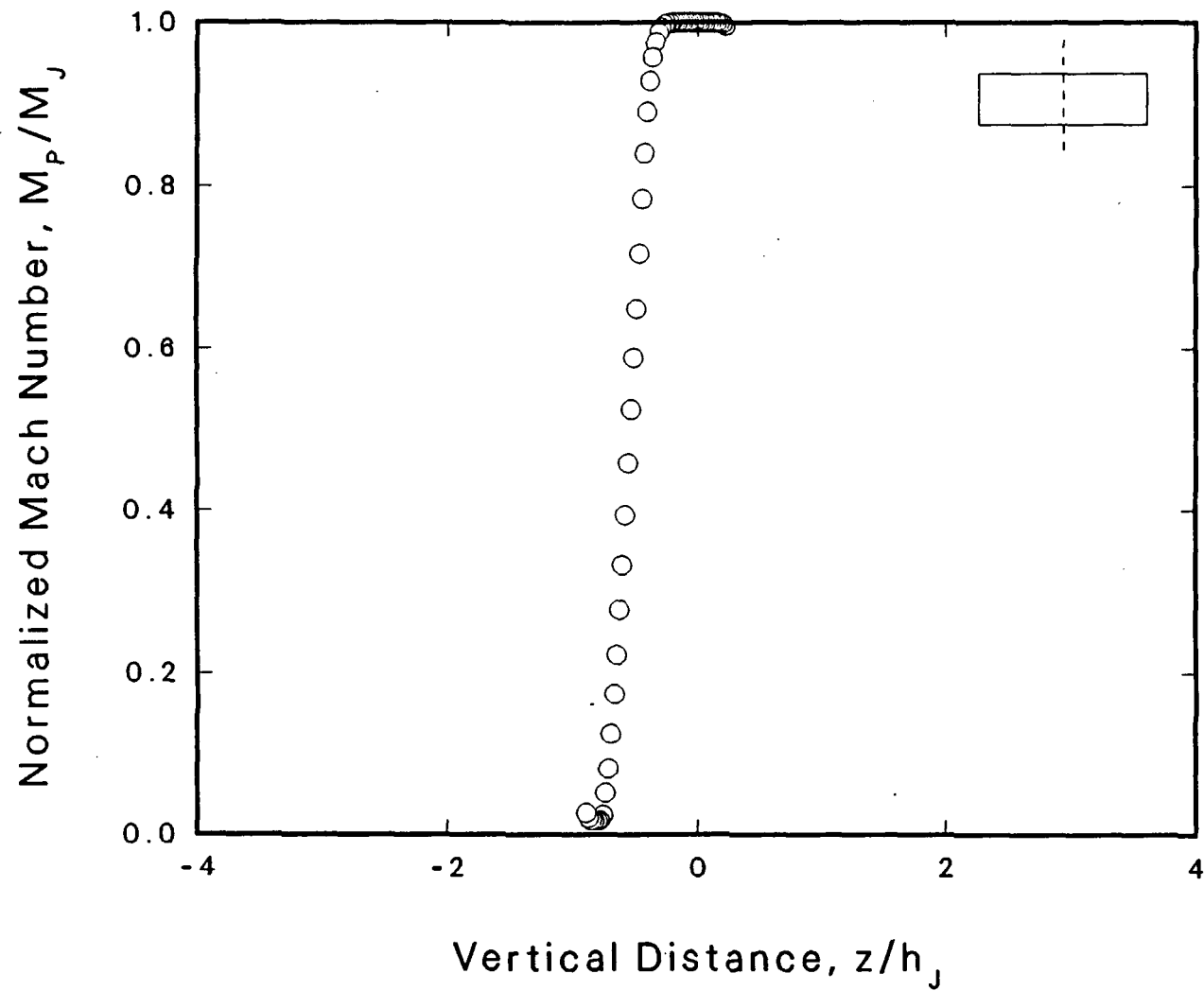
Sym	○	Δ	□
File	TAB129T	TAB127T	TAB125T
Config	0-0	0-0	0-0
M_j	0.798	0.796	0.798
T_{TJ}/T_A	0.98	1.01	1.01
T_{TJ} , K	286.6	285.2	285.1
U_j , mps	255.3	254.0	254.6
Re_{De}	1.079	1.081	1.084
Re_h	0.478	0.479	0.480
Re_w	1.910	1.914	1.919
p_A , kPa	98.307	98.307	98.171
T_A , K	291.8	283.5	283.5
De_j , mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	-1.0	-0.5	0.4

Figure B.18 Baseline Vertical Mach Number Profile,
 $X/De=7,5,2$, $M_j=0.8$, $T_j/T_0=1$



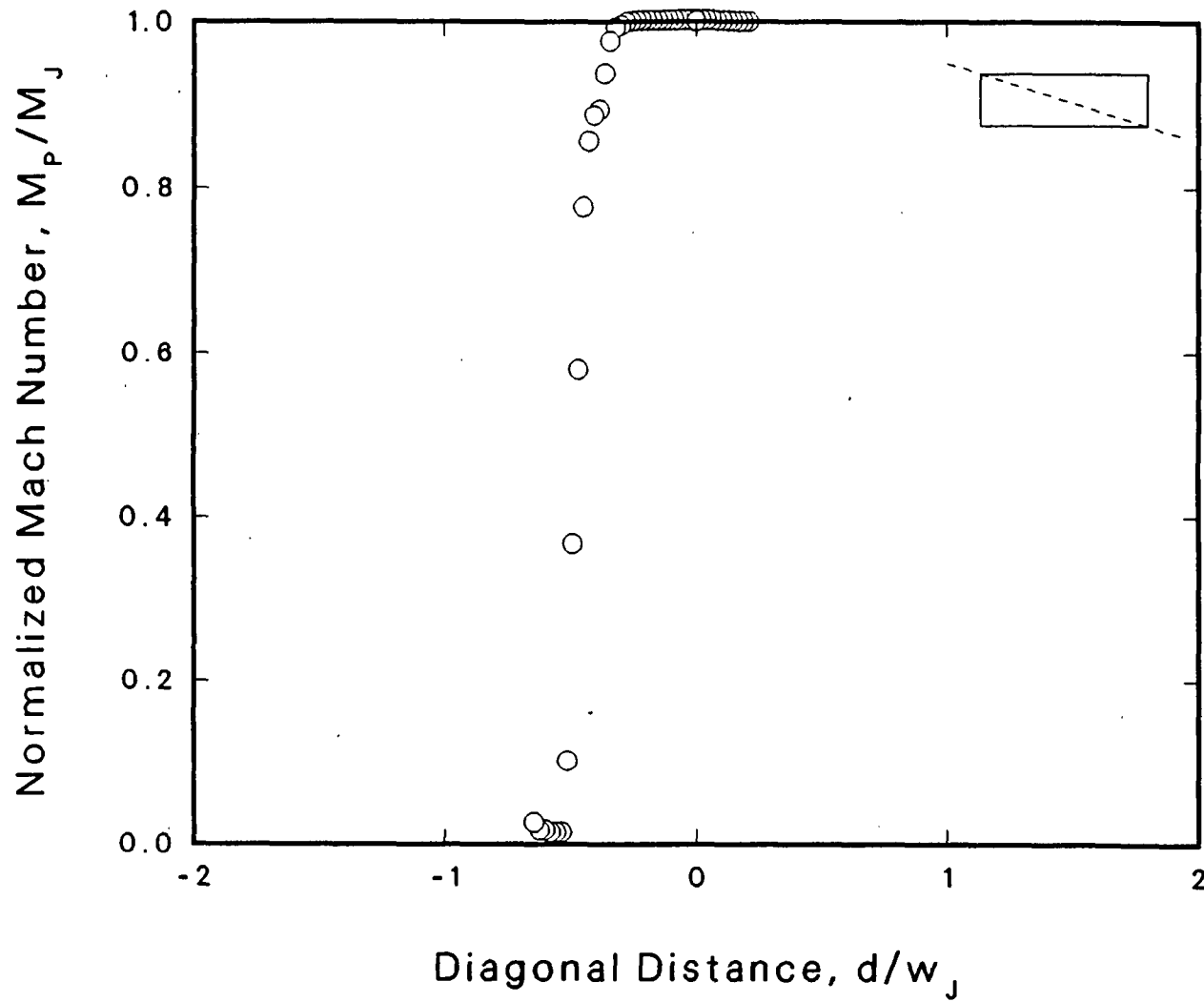
Sym	○	△	□
File	TAB144T	TAB329T	TAB137T
Config	0-0	0-0	0-0
M_j	0.799	0.796	0.798
T_{TJ}/T_A	0.99	1.00	0.99
T_{TJ} , K	285.4	279.8	285.8
U_j , mps	254.9	251.7	254.8
Re_{De}	1.073	1.109	1.077
Re_h	0.475	0.491	0.477
Re_w	1.957	2.023	1.965
p_A , kPa	97.223	98.205	97.833
T_A , K	288.3	278.7	288.5
De_j , mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	3.0	-6.0	-1.0

Figure B.19 Baseline Diagonal Mach Number Profile,
 $X/De=7,5,2$, $M_j=0.8$, $T_j/T_0=1$



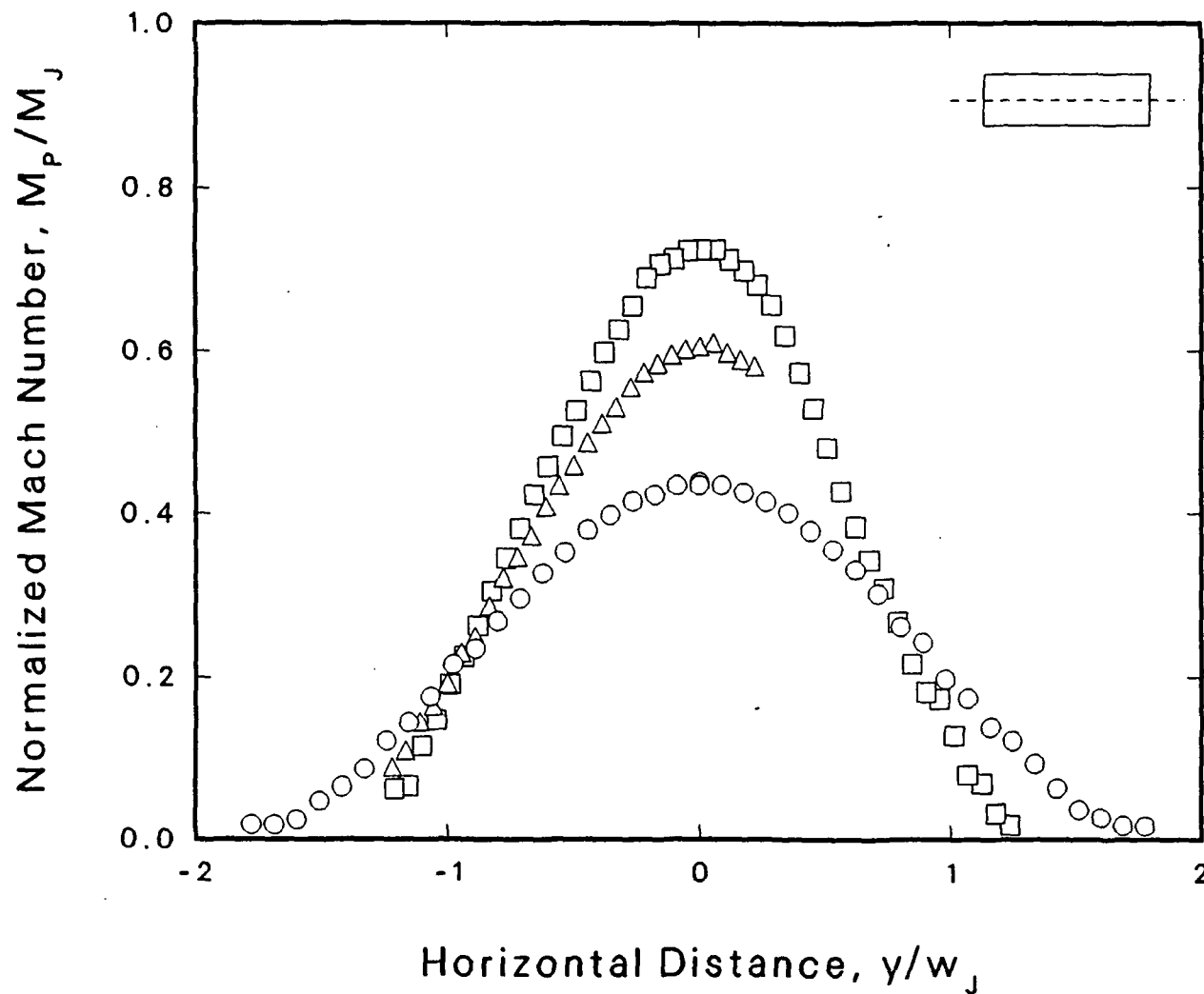
Sym	○
File	TAB135T
Config	0-0
M_j	0.796
T_{Tj}/T_A	0.98
T_{Tj} , K	286.7
U_j , mps	254.7
Re_{De}	1.078
Re_h	0.477
Re_w	1.908
p_A , kPa	98.612
T_A , K	291.6
De_j , mm	50.8
X/De_j	1.00
Y/w_j	0.00
ΔZ , mm	0.0

Figure B.20 Baseline Vertical Mach Number Profile,
 $X/De=1$, $M_j=0.8$, $T_j/T_0=1$



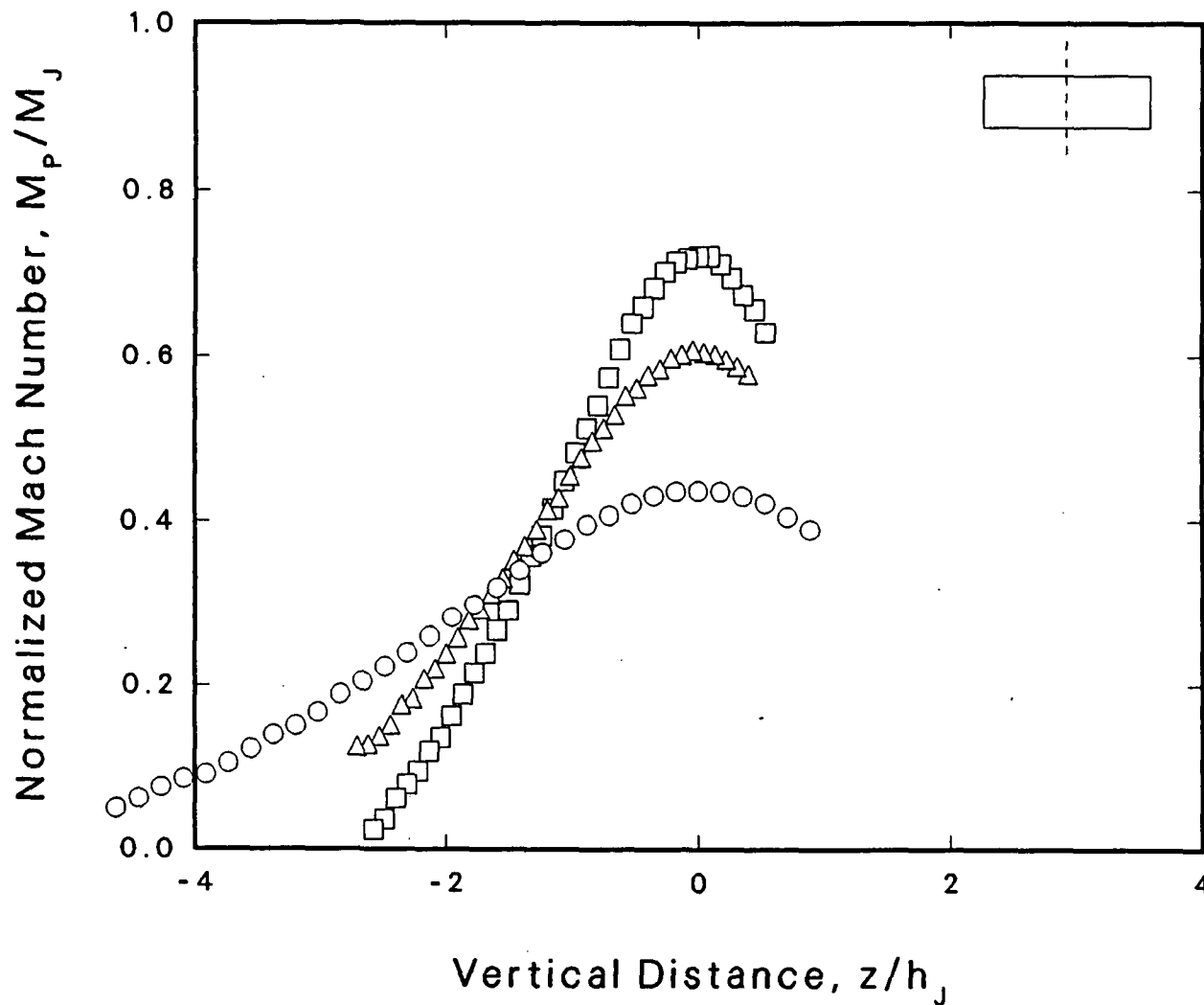
Sym	○
File	TAB136T
Config	0-0
M_j	0.799
T_{TJ}/T_A	1.00
T_{TJ} , K	285.2
U_j , mps	254.9
Re_{De}	1.082
Re_h	0.479
Re_w	1.975
p_A , kPa	97.901
T_A , K	284.6
De_j , mm	50.8
X/De_j	1.00
Z/h_j	0.00
ΔY , mm	0.0

Figure B.21 Baseline Diagonal Mach Number Profile,
 $X/D_e=1$, $M_j=0.8$, $T_j/T_0=1$



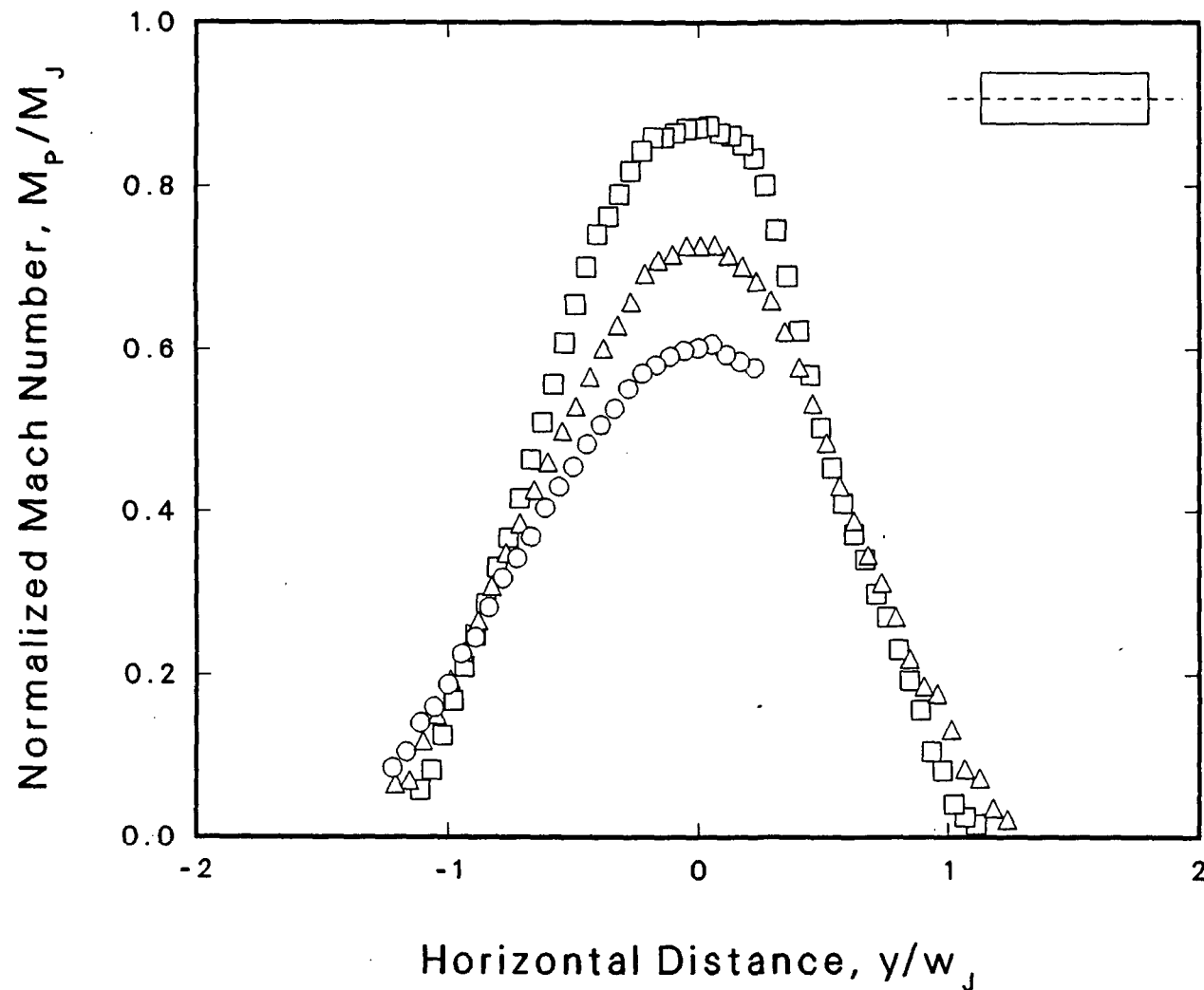
Sym	○	Δ	□
File	TAB356T	TAB332T	TAB350T
Config	0-0	0-0	0-0
M_j	0.804	0.801	0.802
T_{Tj}/T_A	2.29	2.29	2.29
T_{Tj}, K	652.4	624.8	641.6
U_j, mps	385.7	376.5	381.8
Re_{De}	0.388	0.408	0.398
Re_h	0.172	0.181	0.176
Re_w	0.688	0.723	0.705
p_A, kPa	97.765	97.968	98.544
T_A, K	284.4	272.6	280.5
De_j, mm	50.8	50.8	50.8
X/De_j	13.00	9.00	7.00
Z/h_j	0.00	0.00	-0.09
$\Delta Y, mm$	0.0	0.0	-1.0

Figure B.22 Baseline Horizontal Mach Number Profile,
 $X/De=13,9,7$, $M_j=0.8$, $T_j/T_0=2.3$



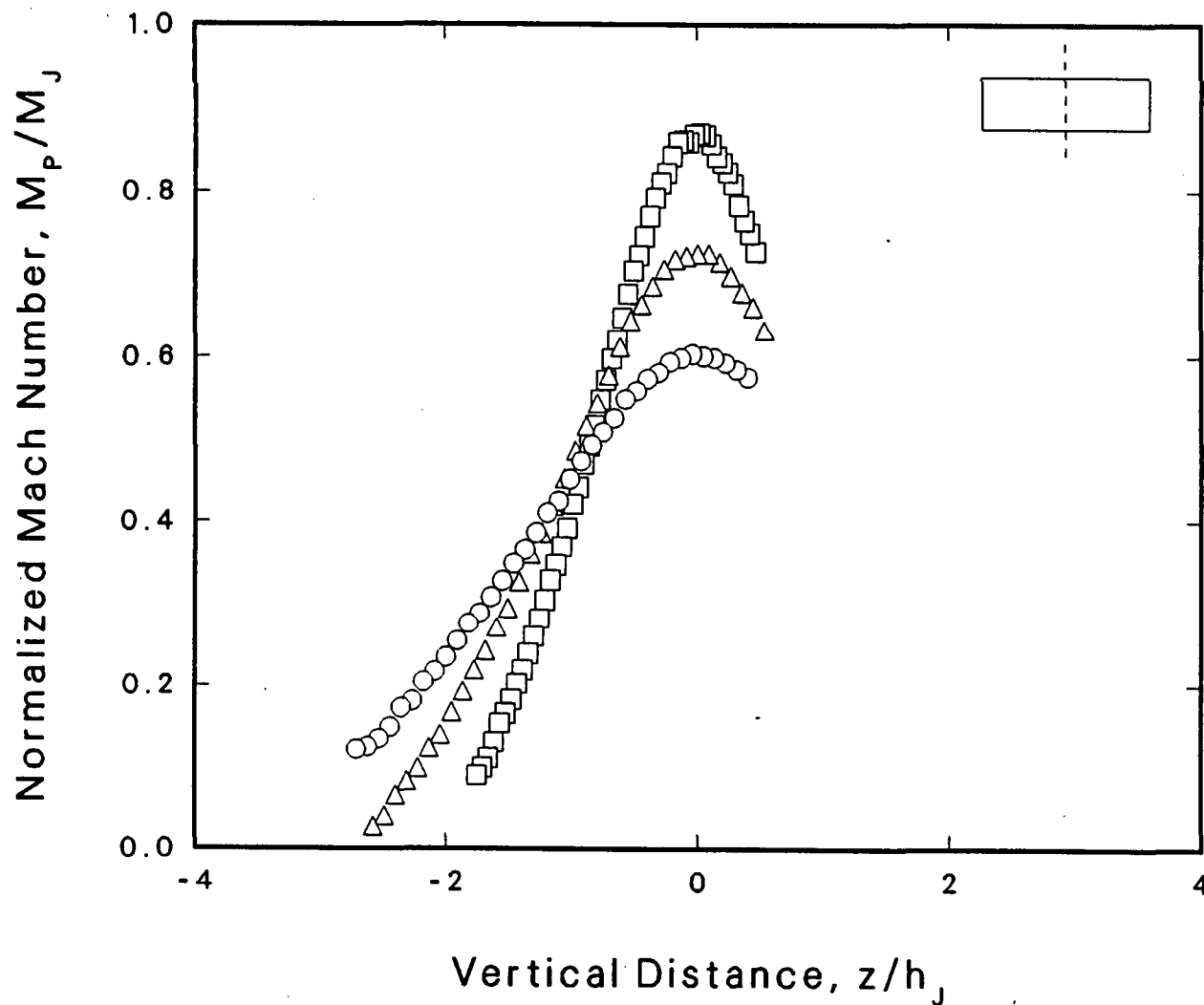
Sym	○	△	□
File	TAB355T	TAB331T	TAB349T
Config	0-0	0-0	0-0
M_j	0.804	0.802	0.803
T_{Tj}/T_A	2.29	2.29	2.30
T_{Tj}, K	651.5	621.9	643.4
U_j, mps	385.5	375.9	382.4
Re_{De}	0.389	0.411	0.397
Re_h	0.172	0.182	0.176
Re_w	0.689	0.727	0.703
p_A, kPa	97.765	98.002	98.578
T_A, K	284.8	272.0	279.4
De_j, mm	50.8	50.8	50.8
X/De_j	13.00	9.00	7.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	0.0	1.0	-2.0

Figure B.23 Baseline Vertical Mach Number Profile,
 $X/D_e=13,9,7$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	○	△	□
File	TAB332T	TAB350T	TAB337T
Config	0-0	0-0	0-0
M_j	0.801	0.802	0.802
T_{Tj}/T_A	2.29	2.29	2.28
T_{Tj}, K	624.8	641.6	632.6
U_j, mps	376.5	381.8	379.0
Re_{De}	0.408	0.398	0.406
Re_h	0.181	0.176	0.180
Re_w	0.723	0.705	0.718
p_A, kPa	97.968	98.544	98.781
T_A, K	272.6	280.5	277.6
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	7.00	5.00
Z/h_j	0.00	-0.09	0.00
$\Delta Y, mm$	0.0	-1.0	0.0

Figure B.24 Baseline Horizontal Mach Number Profile,
 $X/De=9,7,5$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	○	△	□
File	TAB331T	TAB349T	TAB338T
Config	0-0	0-0	0-0
M_j	0.802	0.803	0.803
T_{Tj}/T_A	2.29	2.30	2.27
T_{Tj} , K	621.9	643.4	632.2
U_j , mps	375.9	382.4	379.2
Re_{De}	0.411	0.397	0.407
Re_h	0.182	0.176	0.180
Re_w	0.727	0.703	0.720
p_A , kPa	98.002	98.578	98.781
T_A , K	272.0	279.4	277.9
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	7.00	5.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	1.0	-2.0	-0.5

Figure B.25 Baseline Vertical Mach Number Profile,
 $X/De_j=9,7,5$, $M_j=0.8$, $T_j/T_0=2.3$

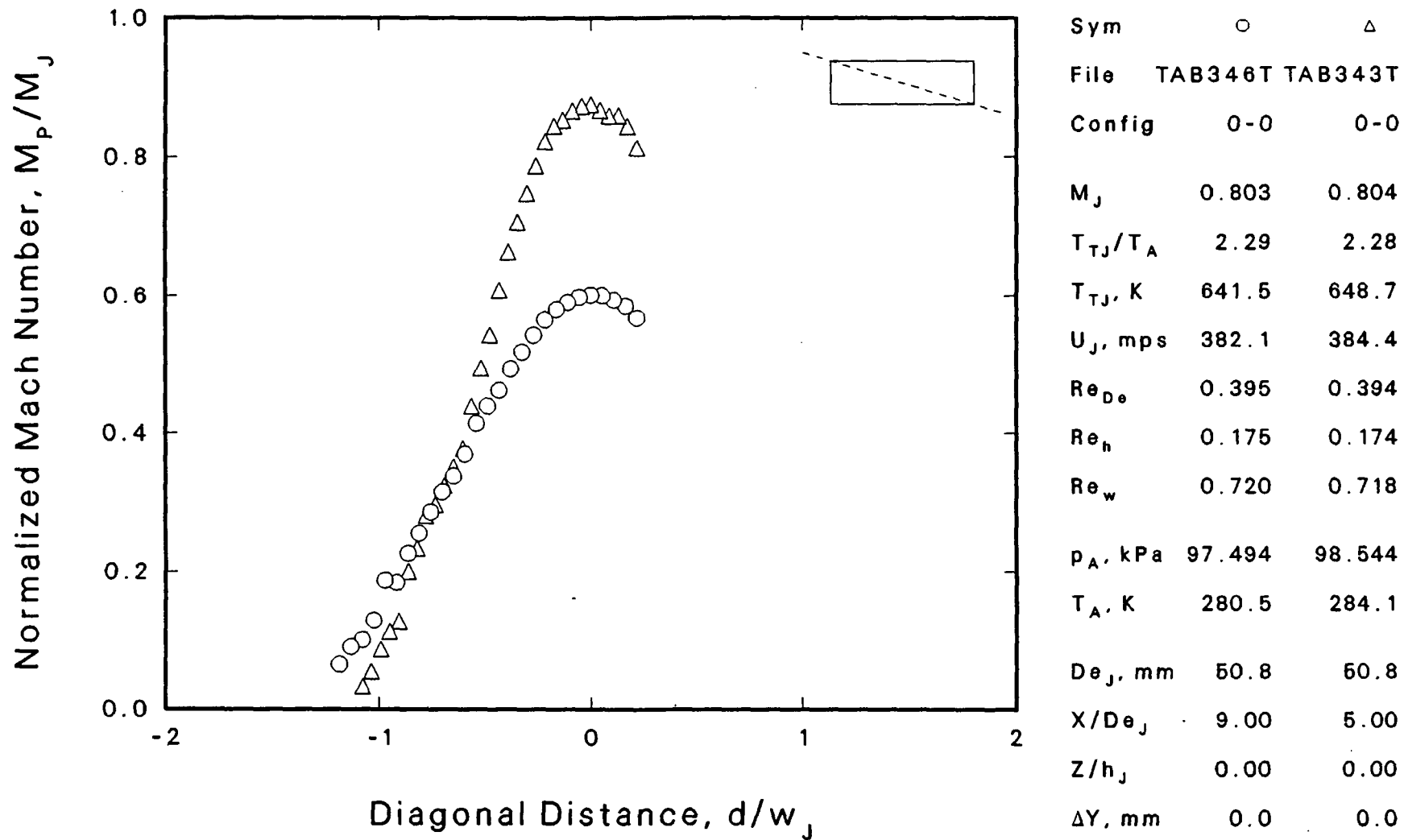
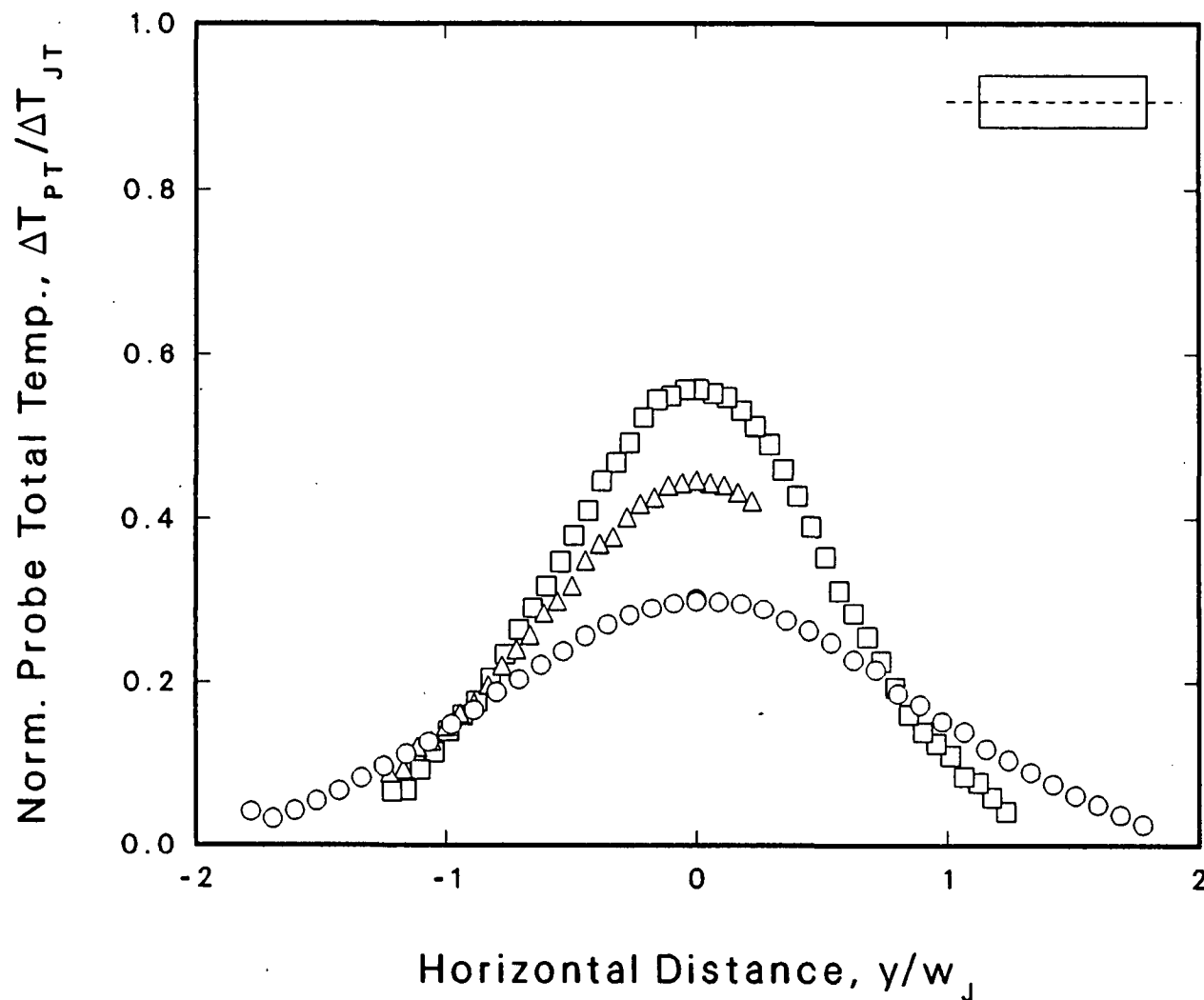
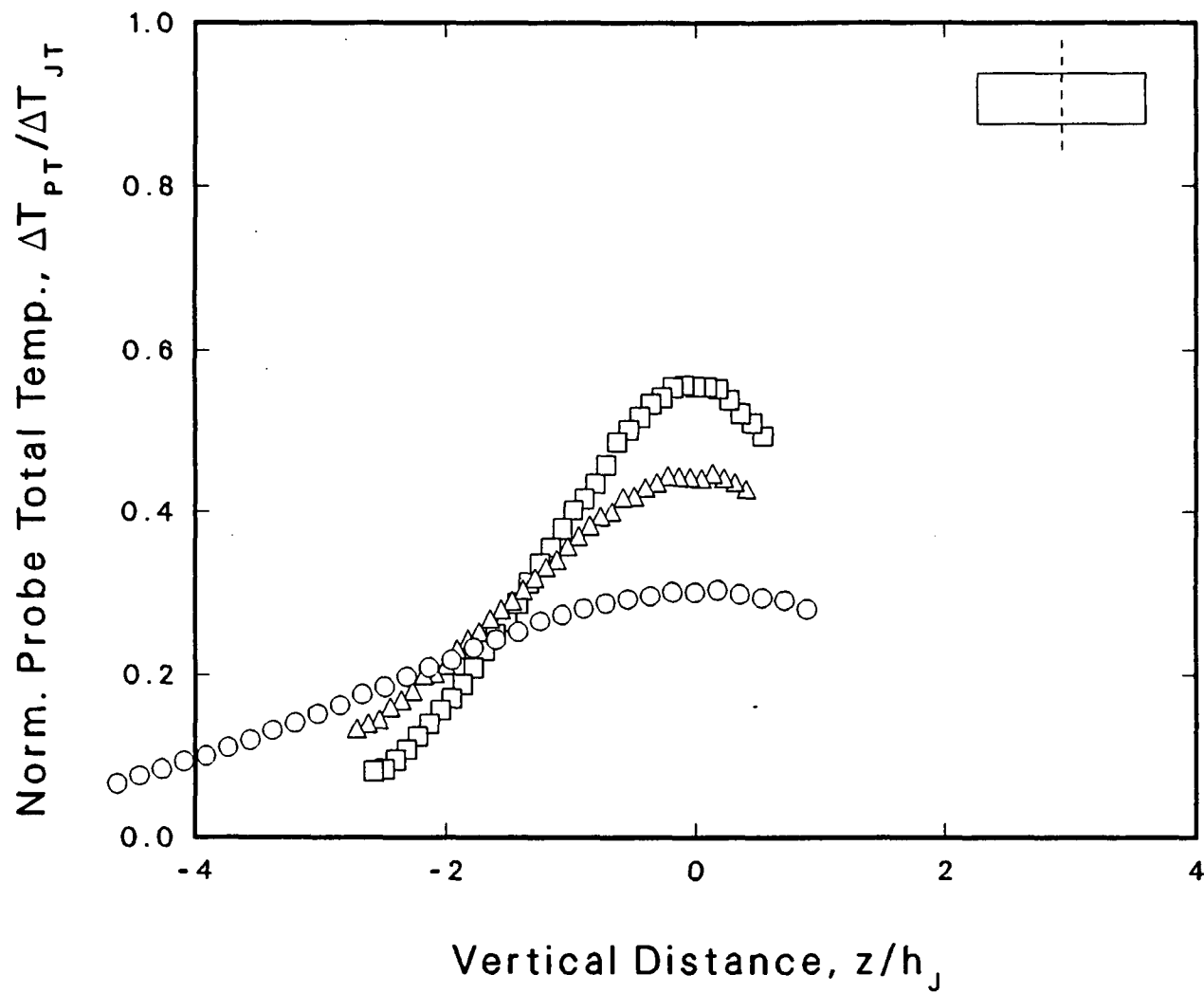


Figure B.26 Baseline Diagonal Mach Number Profile,
 $X/D_e=9,5$, $M_j=0.8$, $T_j/T_0=2.3$



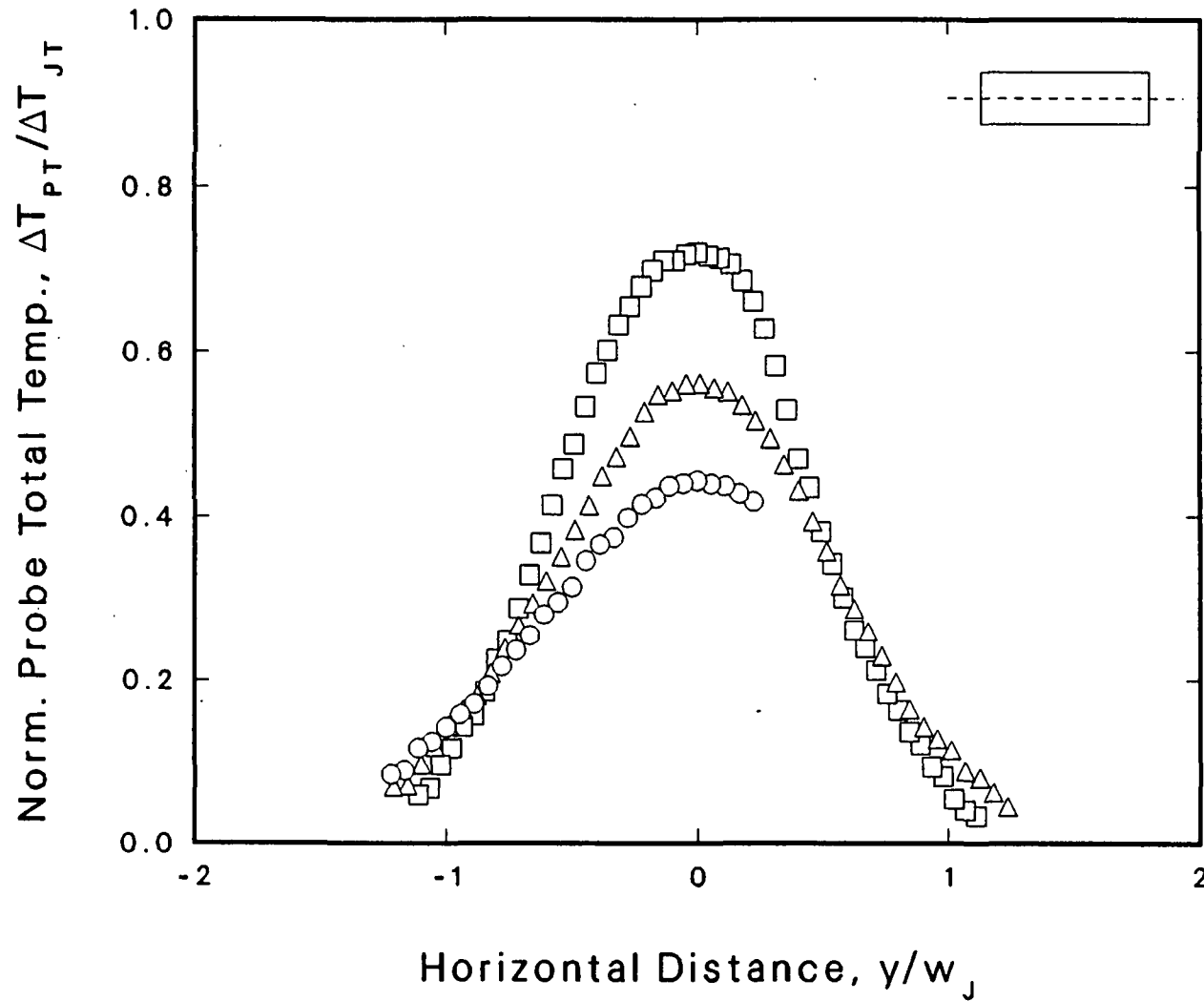
Sym	○	Δ	□
File	TAB356T	TAB332T	TAB350T
Config	0-0	0-0	0-0
M_J	0.804	0.801	0.802
T_{TJ}/T_A	2.29	2.29	2.29
T_{TJ}, K	652.4	624.8	641.6
U_J, mps	385.7	376.5	381.8
Re_{De}	0.388	0.408	0.398
Re_h	0.172	0.181	0.176
Re_w	0.688	0.723	0.705
p_A, kPa	97.765	97.968	98.544
T_A, K	284.4	272.6	280.5
De_J, mm	50.8	50.8	50.8
X/De_J	13.00	9.00	7.00
Z/h_J	0.00	0.00	-0.09
$\Delta Y, mm$	0.0	0.0	-1.0

Figure B.27 Baseline Horizontal Temperature Profile,
 $X/De=13,9,7$, $M_J=0.8$, $T_J/T_0=2.3$



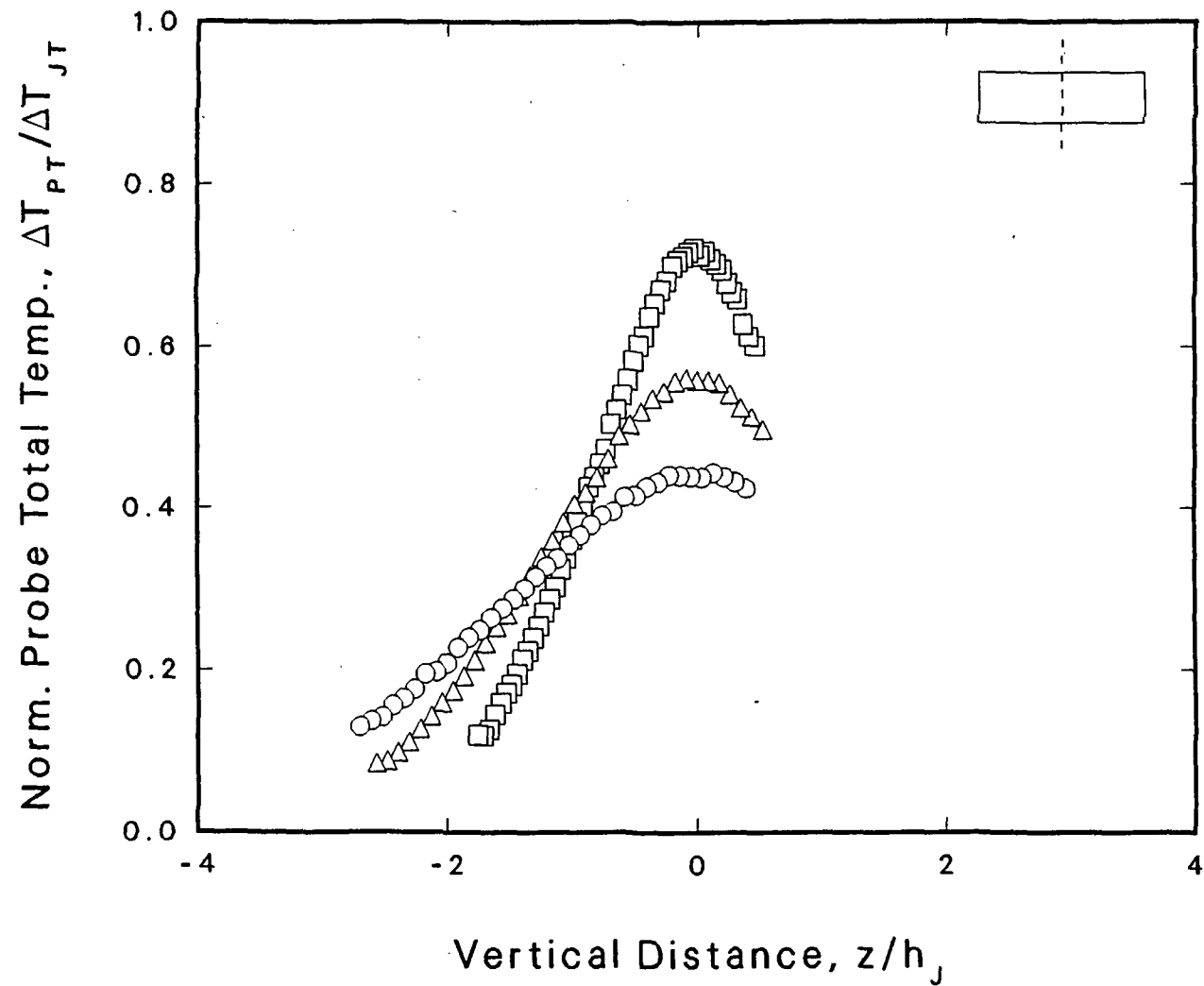
Sym	○	Δ	□
File	TAB355T	TAB331T	TAB349T
Config	0-0	0-0	0-0
M_J	0.804	0.802	0.803
T_{TJ}/T_A	2.29	2.29	2.30
T_{TJ}, K	651.5	621.9	643.4
U_J, mps	385.5	375.9	382.4
Re_{De}	0.389	0.411	0.397
Re_h	0.172	0.182	0.176
Re_w	0.689	0.727	0.703
p_A, kPa	97.765	98.002	98.578
T_A, K	284.8	272.0	279.4
De_J, mm	50.8	50.8	50.8
X/De_J	13.00	9.00	7.00
Y/w_J	0.00	0.00	0.00
$\Delta Z, mm$	0.0	1.0	-2.0

Figure B.28 Baseline Vertical Temperature Profile,
 $X/D_e=13,9,7$, $M_j=0.8$, $T_j/T_0=2.3$



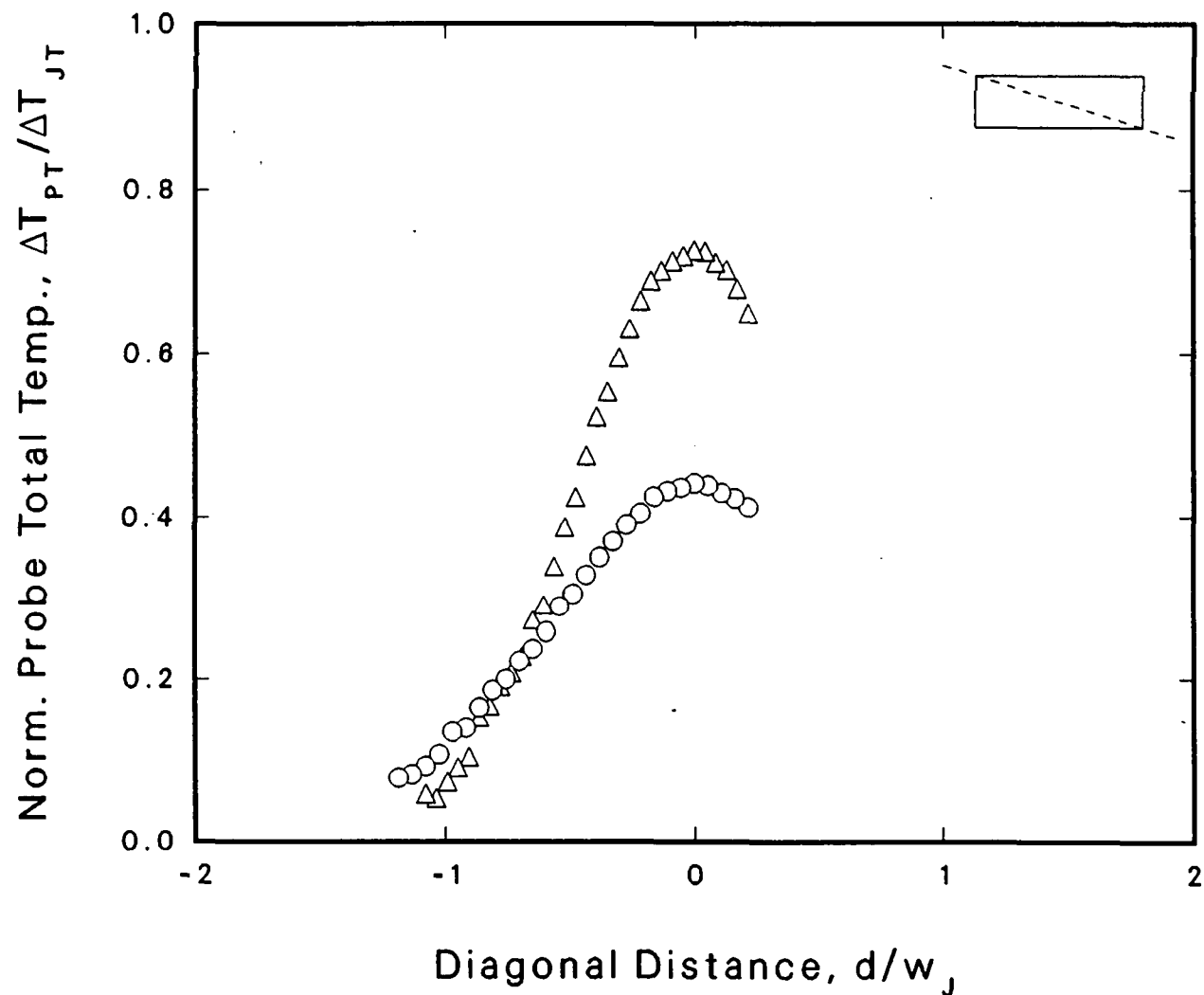
Sym	○	Δ	□
File	TAB332T	TAB350T	TAB337T
Config	0-0	0-0	0-0
M_J	0.801	0.802	0.802
T_{TJ}/T_A	2.29	2.29	2.28
T_{TJ}, K	624.8	641.6	632.6
U_J, mps	376.5	381.8	379.0
Re_{De}	0.408	0.398	0.406
Re_h	0.181	0.176	0.180
Re_w	0.723	0.705	0.718
p_A, kPa	97.968	98.544	98.781
T_A, K	272.6	280.5	277.6
De_J, mm	50.8	50.8	50.8
X/De_J	9.00	7.00	5.00
Z/h_J	0.00	-0.09	0.00
$\Delta Y, mm$	0.0	-1.0	0.0

Figure B.29 Baseline Horizontal Temperature Profile,
 $X/De=9,7,5$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	○	△	□
File	TAB331T	TAB349T	TAB338T
Config	0-0	0-0	0-0
M_J	0.802	0.803	0.803
T_{TJ}/T_A	2.29	2.30	2.27
T_{TJ}, K	621.9	643.4	632.2
U_J, mps	375.9	382.4	379.2
Re_{De}	0.411	0.397	0.407
Re_h	0.182	0.176	0.180
Re_w	0.727	0.703	0.720
p_A, kPa	98.002	98.578	98.781
T_A, K	272.0	279.4	277.9
De_J, mm	50.8	50.8	50.8
X/De_J	9.00	7.00	5.00
Y/w_J	0.00	0.00	0.00
$\Delta Z, mm$	1.0	-2.0	-0.6

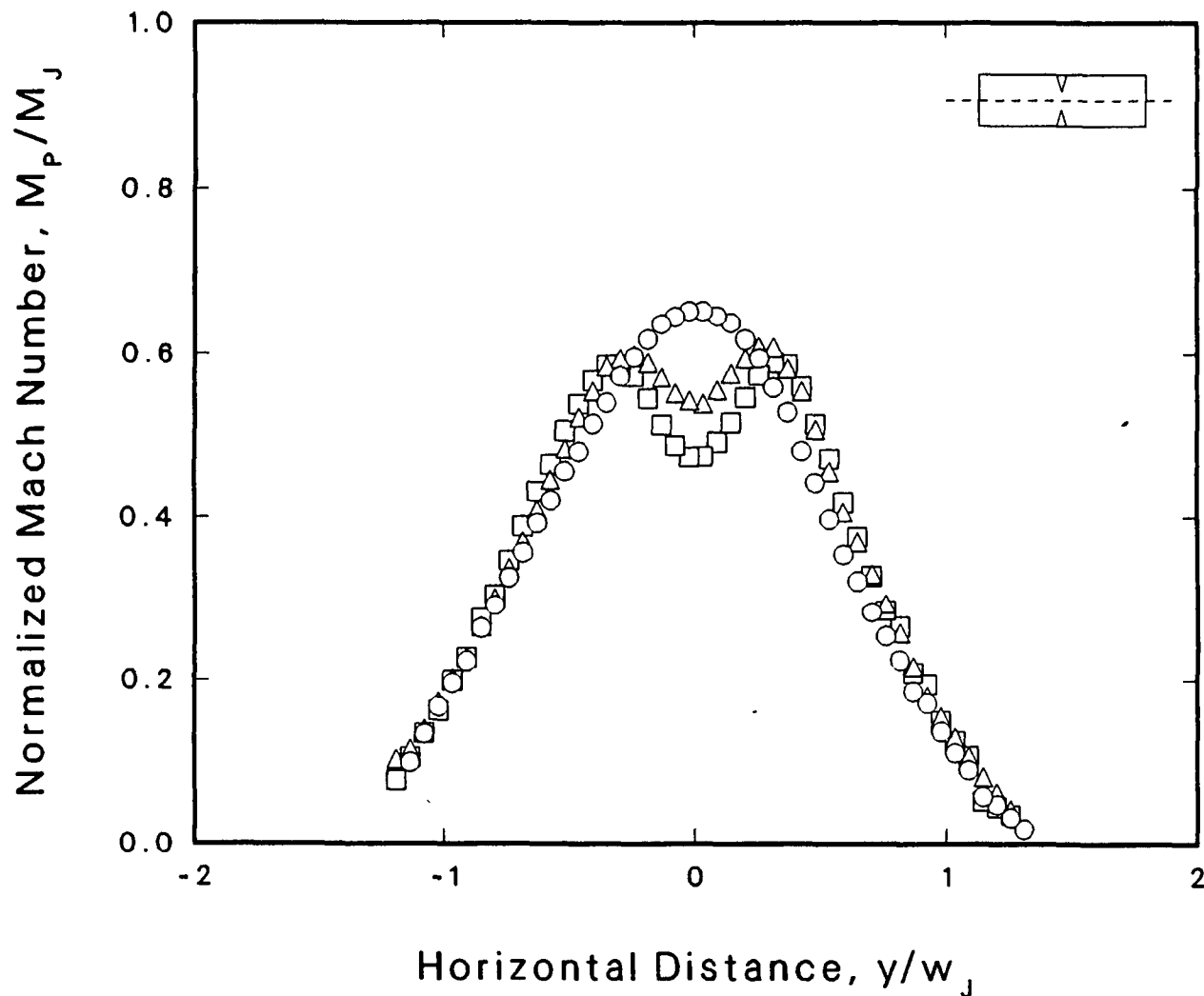
Figure B.30 Baseline Vertical Temperature Profile,
 $X/De=9,7,5$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	○	Δ
File	TAB346T	TAB343T
Config	0-0	0-0
M_J	0.803	0.804
T_{TJ}/T_A	2.29	2.28
T_{TJ}, K	641.5	648.7
U_J, mps	382.1	384.4
Re_{De}	0.395	0.394
Re_h	0.175	0.174
Re_w	0.720	0.718
p_A, kPa	97.494	98.544
T_A, K	280.5	284.1
De_J, mm	50.8	50.8
X/De_J	9.00	5.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	0.0

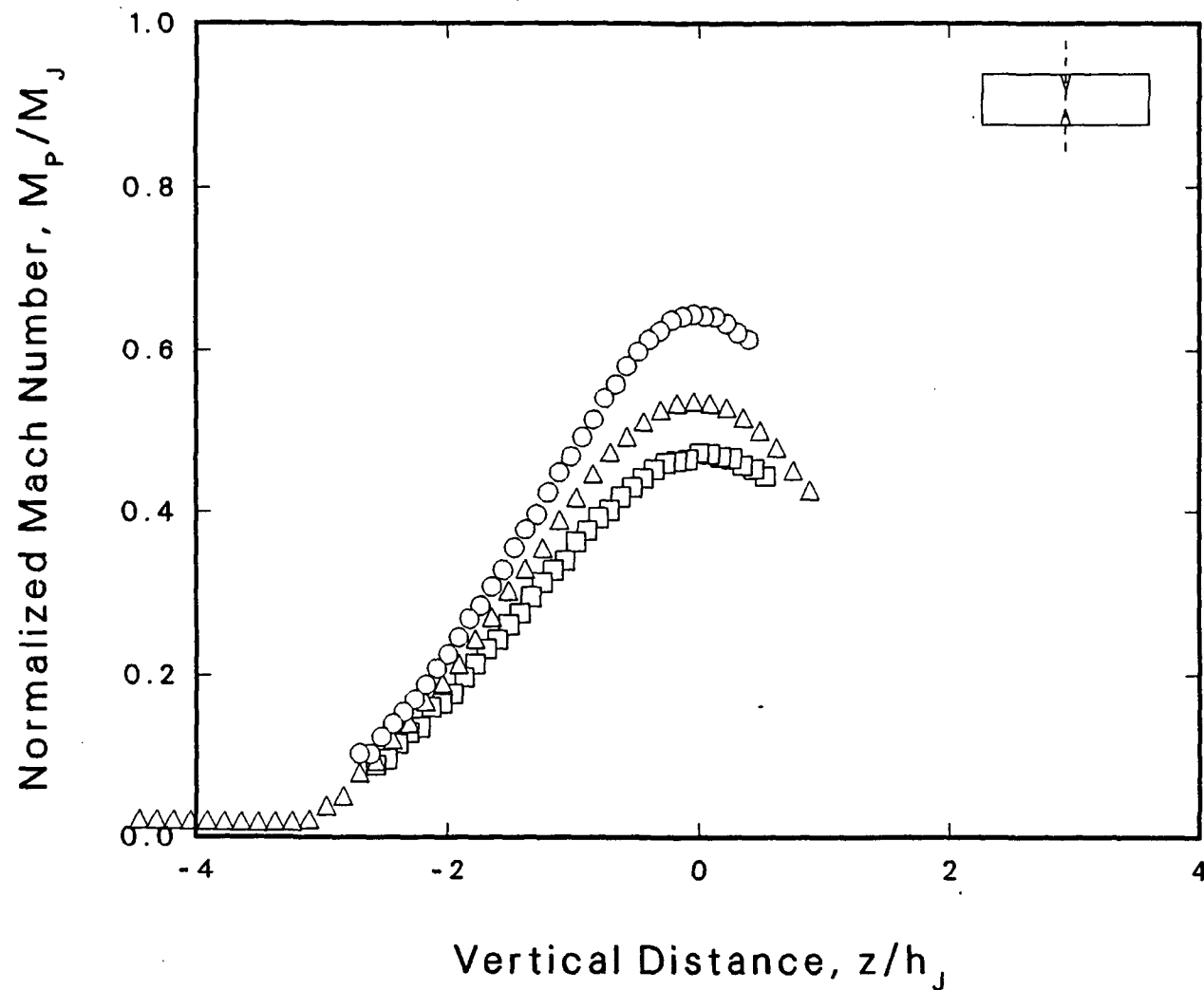
Figure B.31 Baseline Diagonal Temperature Profile,
 $X/De=9,5$, $M_j=0.8$, $T_j/T_0=2.3$

B-3.2 Mixing Modification for Unheated Subsonic Jets



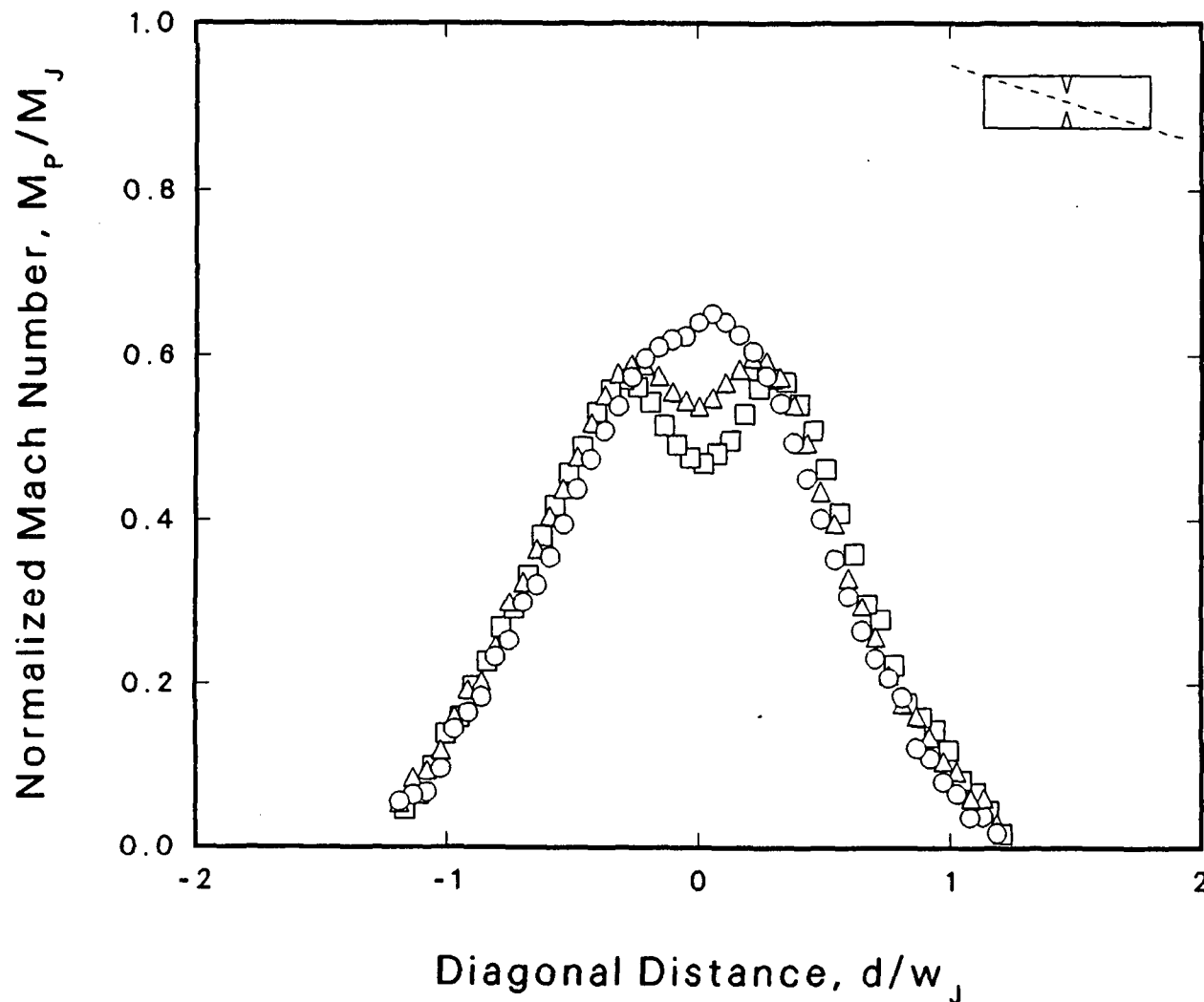
Sym	○	△	□
File	TAB147T	TAB157T	TAB149T
Config	0-0	I-A	I-B
M_j	0.800	0.799	0.799
T_{TJ}/T_A	0.97	1.01	0.97
T_{TJ} , K	285.5	284.0	286.0
U_j , mps	255.2	254.5	255.3
Re_{De}	1.087	1.095	1.083
Re_h	0.482	0.485	0.480
Re_w	1.925	1.938	1.917
p_A , kPa	98.375	98.442	98.239
T_A , K	294.6	281.9	294.6
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	-8.0	-3.0	-3.0

Figure B.32 Configuration I, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$



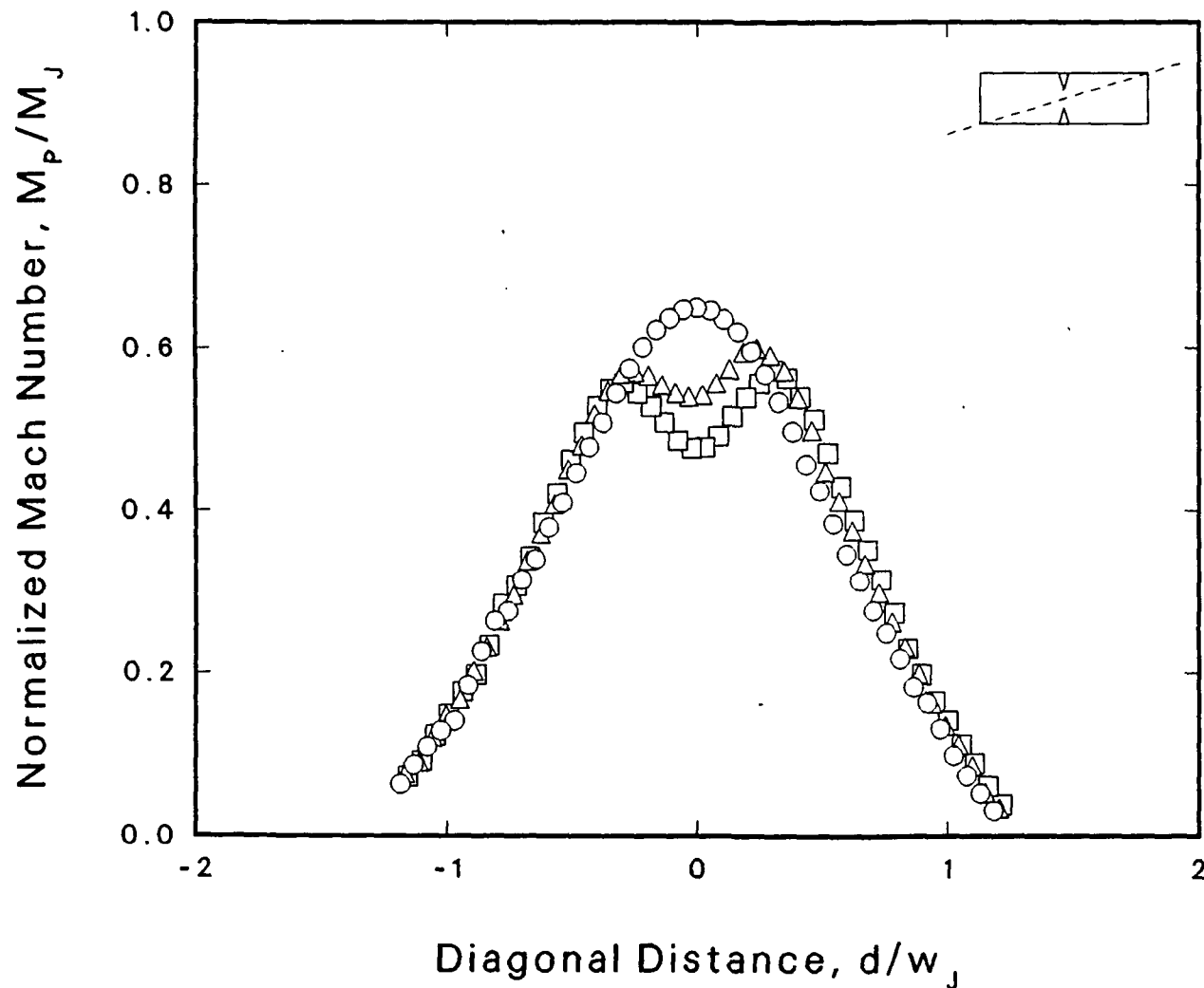
Sym	○	Δ	□
File	TAB146T	TAB158T	TAB148T
Config	0-0	I-A	I-B
M_j	0.800	0.797	0.797
T_{Tj}/T_A	0.97	1.00	0.97
T_{Tj} , K	285.8	284.1	286.3
U_j , mps	255.4	253.9	254.8
Re_{D_e}	1.086	1.091	1.078
Re_h	0.481	0.483	0.478
Re_w	1.922	1.932	1.909
p_A , kPa	98.375	98.510	98.341
T_A , K	294.9	282.9	294.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	1.0	0.0	-2.0

Figure B.33 Configuration I, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



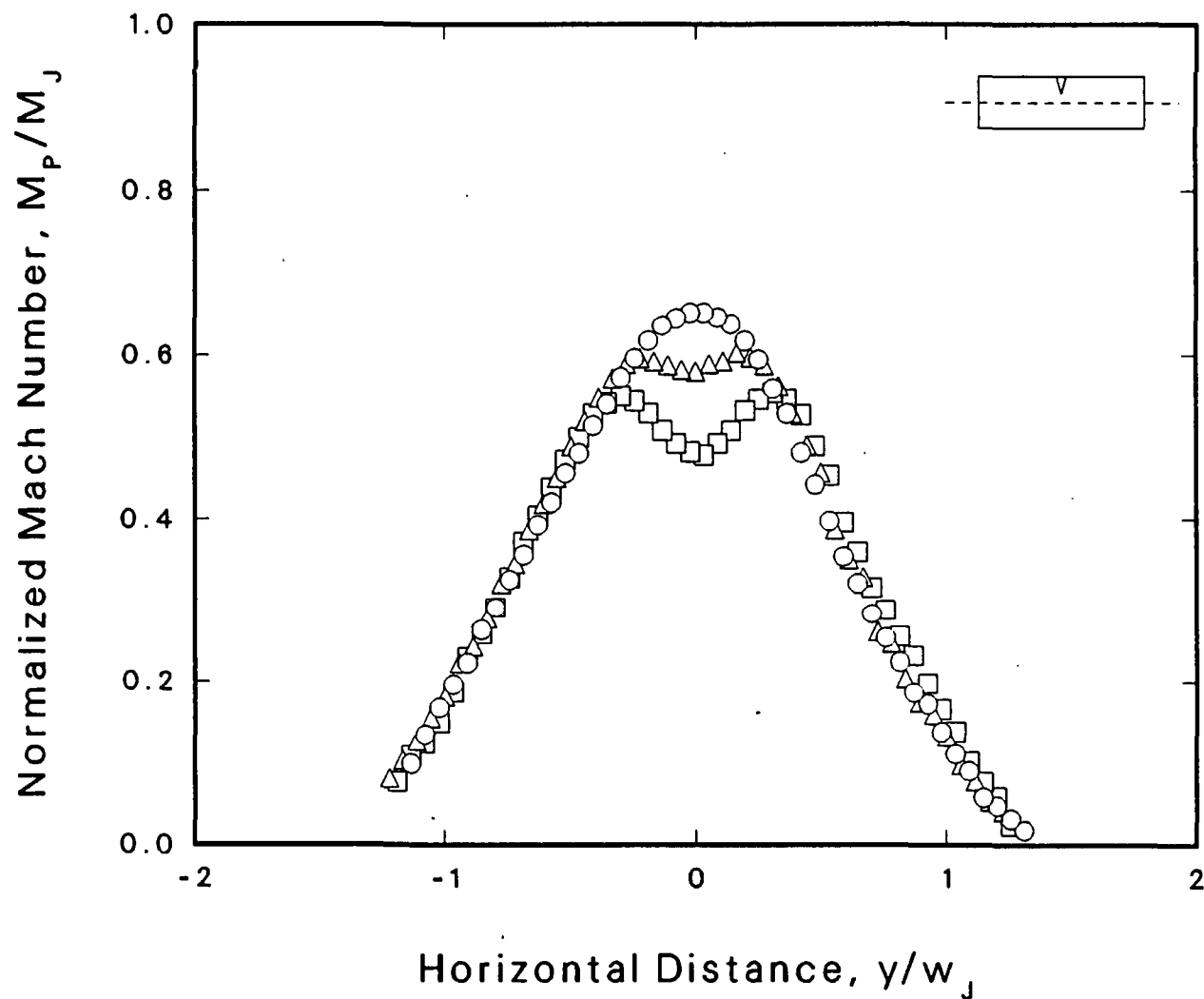
Sym	○	Δ	□
File	TAB165T	TAB168T	TAB167T
Config	0-0	I-A	I-B
M_j	0.797	0.797	0.797
T_{Tj}/T_A	0.98	1.00	1.00
T_{Tj} , K	285.1	283.9	283.8
U_j , mps	254.3	253.6	253.7
Re_{De}	1.088	1.091	1.092
Re_h	0.482	0.483	0.484
Re_w	1.985	1.990	1.992
p_A , kPa	98.713	98.476	98.442
T_A , K	290.6	284.6	282.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	-2.0

Figure B.34 Configuration I, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$



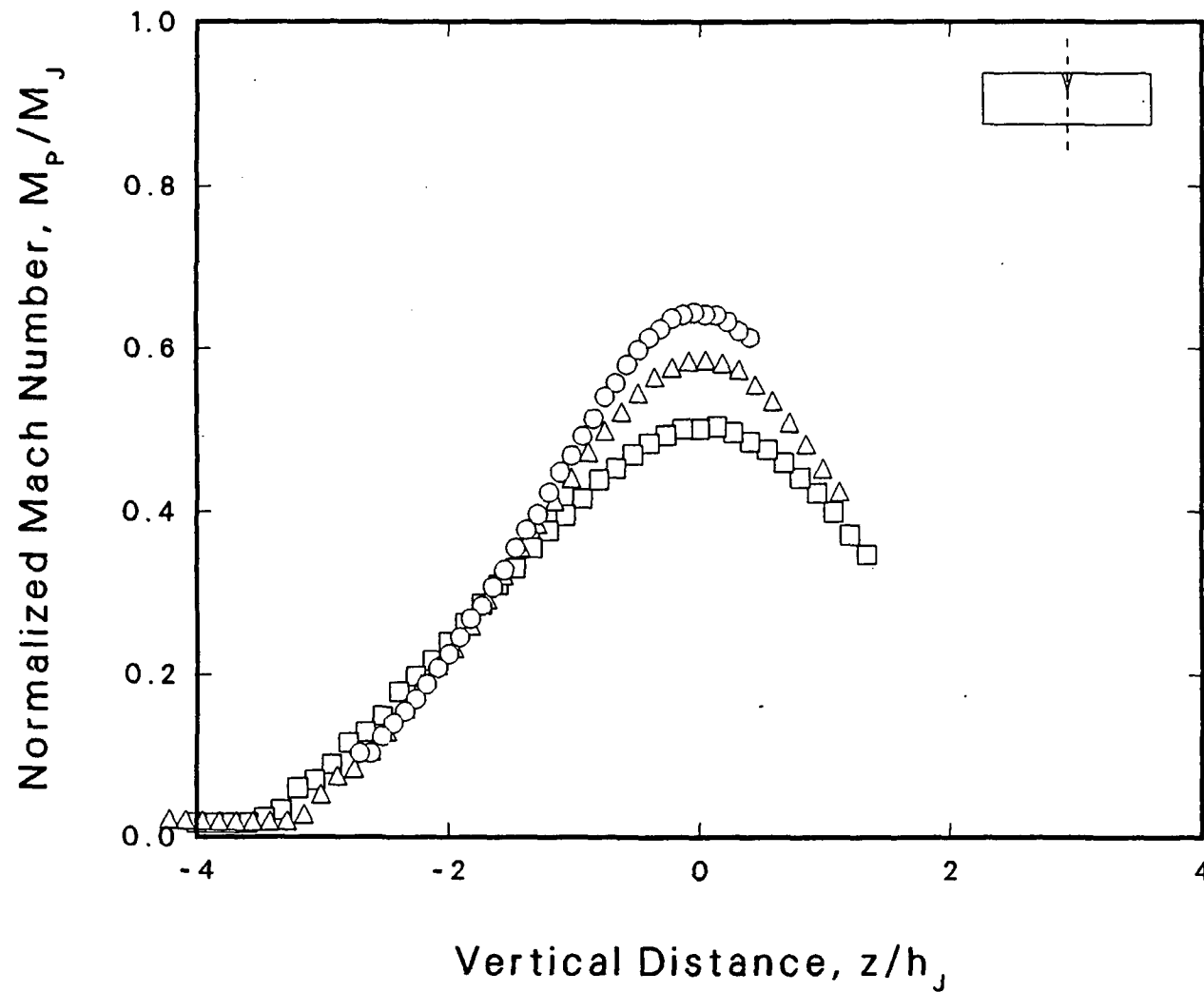
Sym	○	Δ	□
File	TAB175T	TAB176T	TAB180T
Config	0-0	I-A	I-B
M_j	0.798	0.799	0.798
T_{TJ}/T_A	1.00	1.00	1.00
T_{TJ}, K	284.2	284.1	283.8
U_j, mps	254.0	254.3	254.0
Re_{D_e}	1.091	1.092	1.090
Re_h	0.483	0.484	0.483
Re_w	1.991	1.993	1.990
p_A, kPa	98.476	98.341	98.138
T_A, K	285.2	285.3	283.1
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	-2.0	-3.0

Figure B.35 Configuration I, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



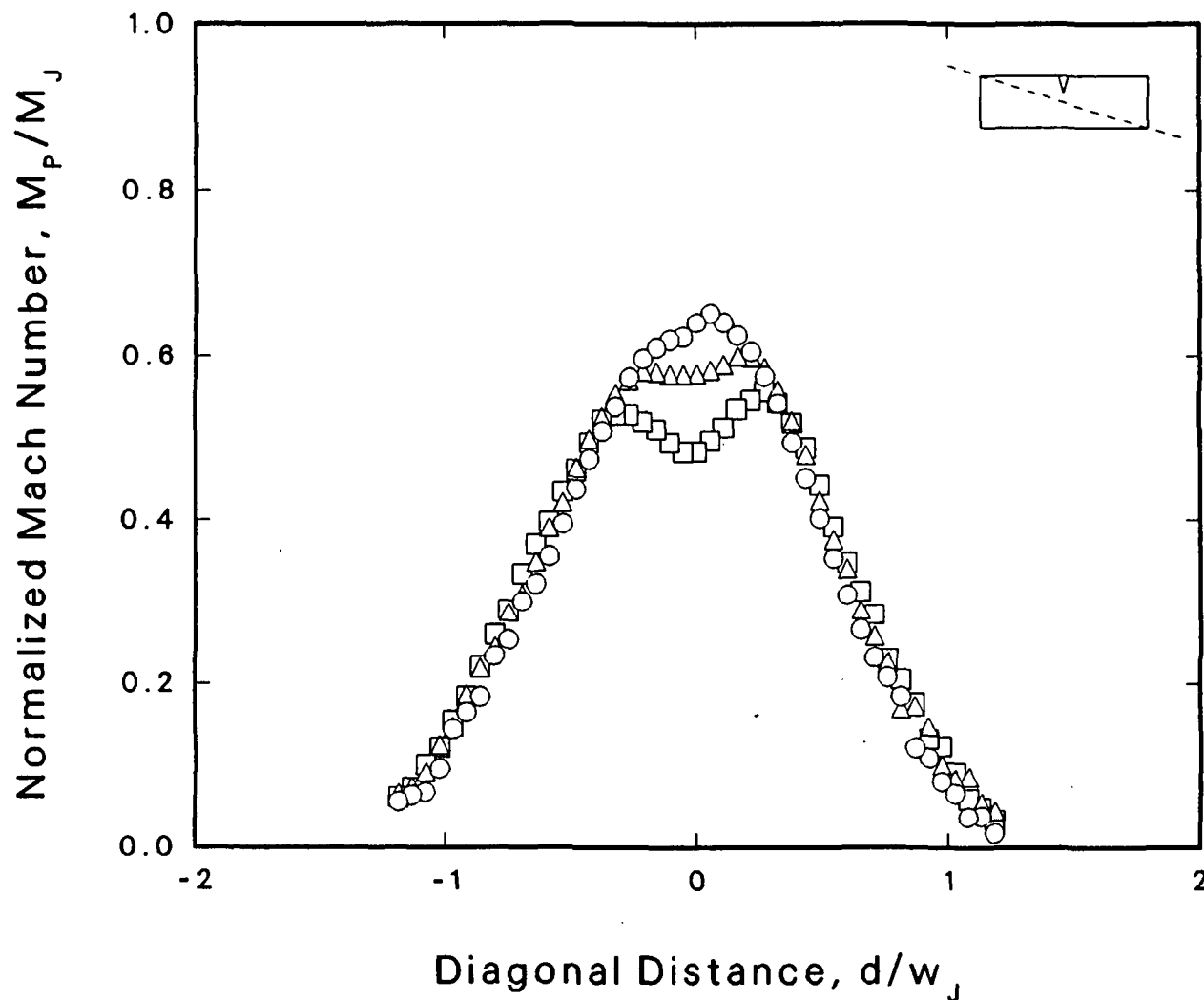
Sym	○	△	□
File	TAB147T	TAB161T	TAB155T
Config	0-0	III-A	III-B
M_j	0.800	0.798	0.798
T_{TJ}/T_A	0.97	0.99	0.97
T_{TJ} , K	285.5	284.9	286.3
U_j , mps	255.2	254.4	255.1
Re_{De}	1.087	1.089	1.074
Re_h	0.482	0.482	0.476
Re_w	1.925	1.927	1.901
p_A , kPa	98.375	98.544	97.833
T_A , K	294.6	288.8	296.1
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	-8.0	0.0	-3.0

Figure B.36 Configuration III, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



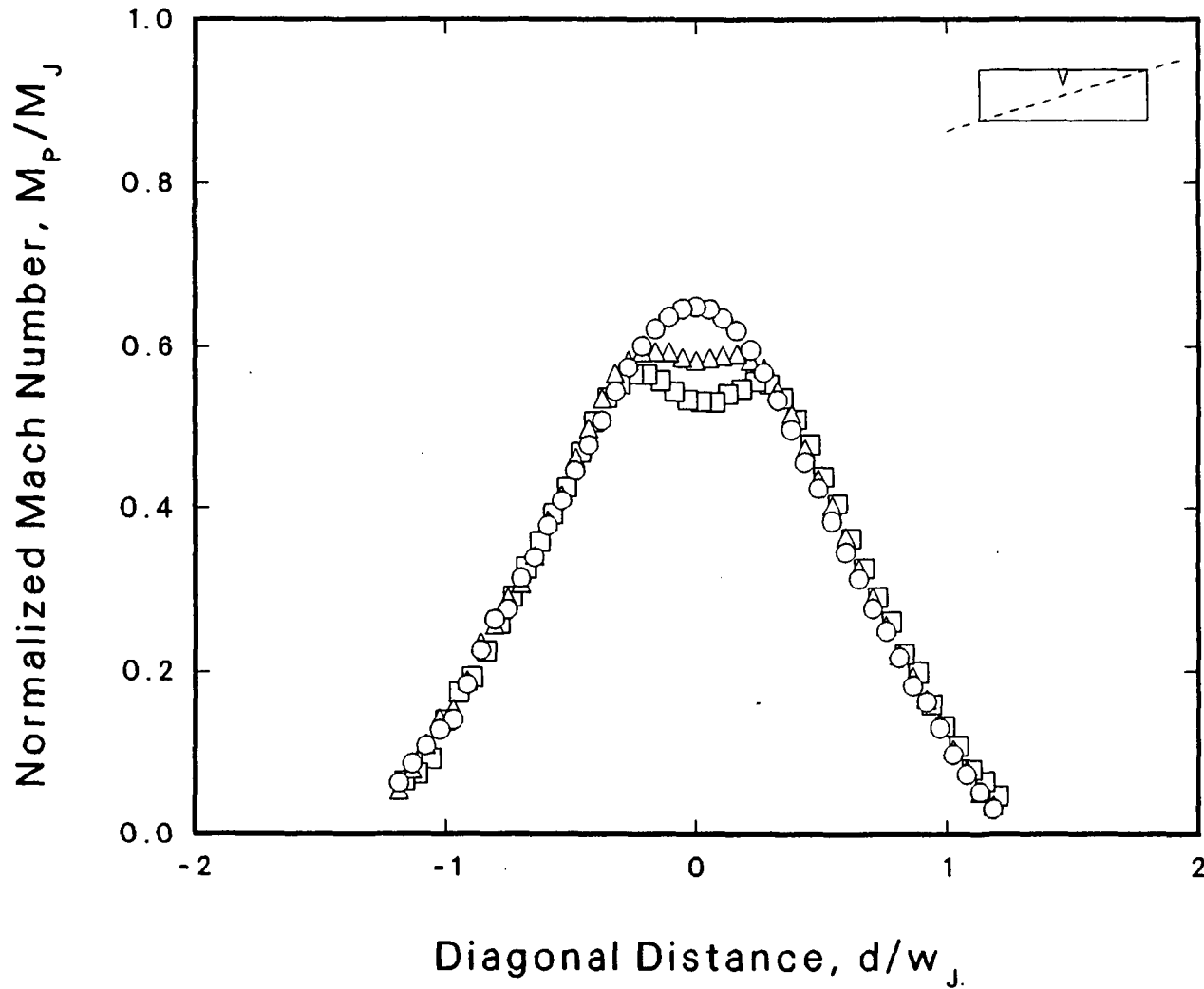
Sym	○	Δ	□
File	TAB146T	TAB162T	TAB156T
Config	0-0	III-A	III-B
M_j	0.800	0.796	0.805
T_{Tj}/T_A	0.97	0.99	0.97
T_{Tj} , K	285.8	284.9	286.0
U_j , mps	255.4	253.9	256.8
Re_{De}	1.086	1.085	1.087
Re_h	0.481	0.481	0.481
Re_w	1.922	1.921	1.924
p_A , kPa	98.375	98.510	97.799
T_A , K	294.9	289.1	295.6
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	1.0	-5.0	-10.0

Figure B.37 Configuration III, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



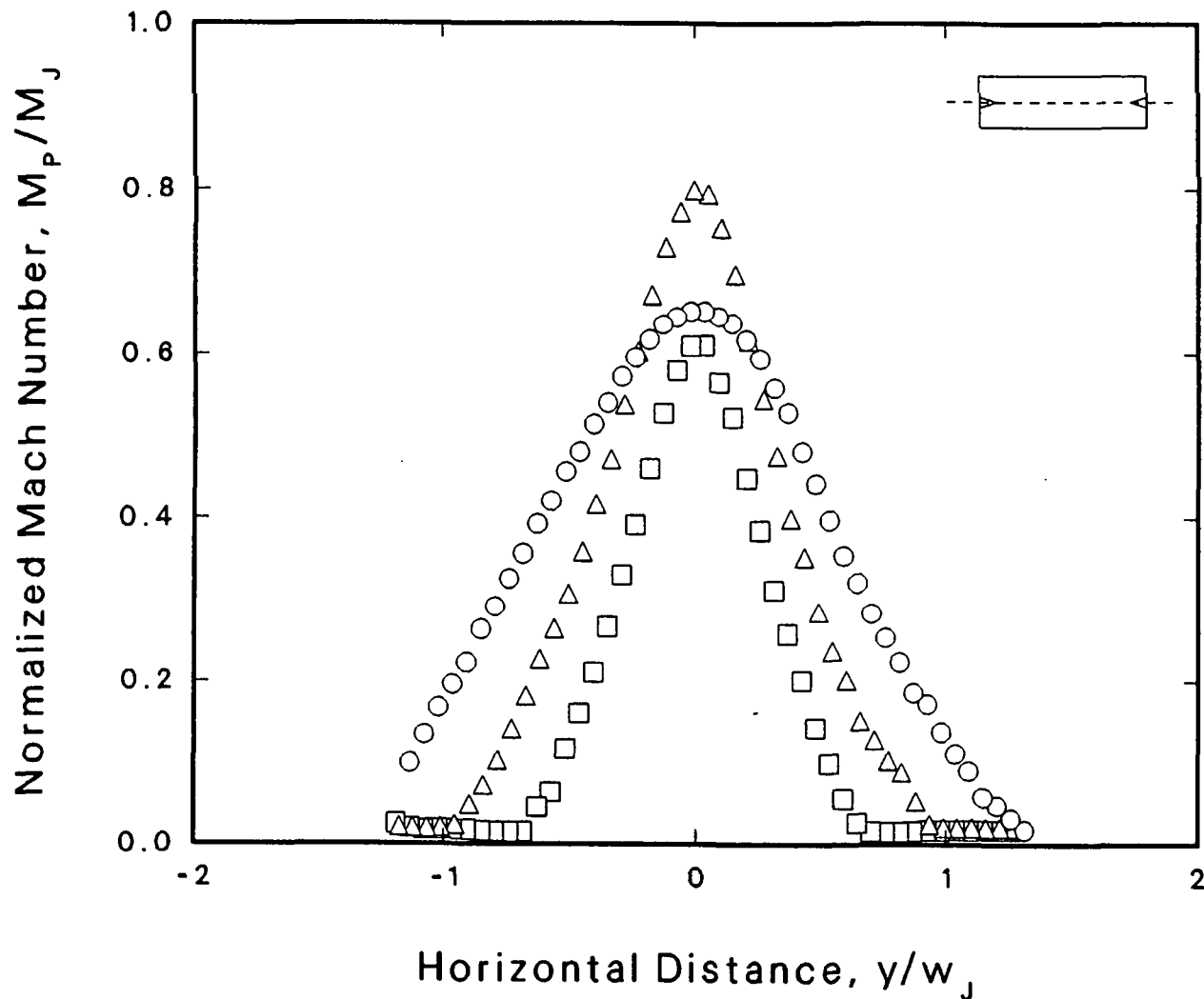
Sym	○	△	□
File	TAB165T	TAB169T	TAB170T
Config	0-0	III-A	III-B
M_j	0.797	0.798	0.799
T_{TJ}/T_A	0.98	0.99	0.98
T_{TJ} , K	285.1	284.8	284.9
U_j , mps	254.3	254.4	254.7
Re_{De}	1.088	1.087	1.087
Re_h	0.482	0.482	0.481
Re_w	1.985	1.984	1.983
p_A , kPa	98.713	98.341	98.239
T_A , K	290.6	288.5	289.5
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure B.38 Configuration III, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$



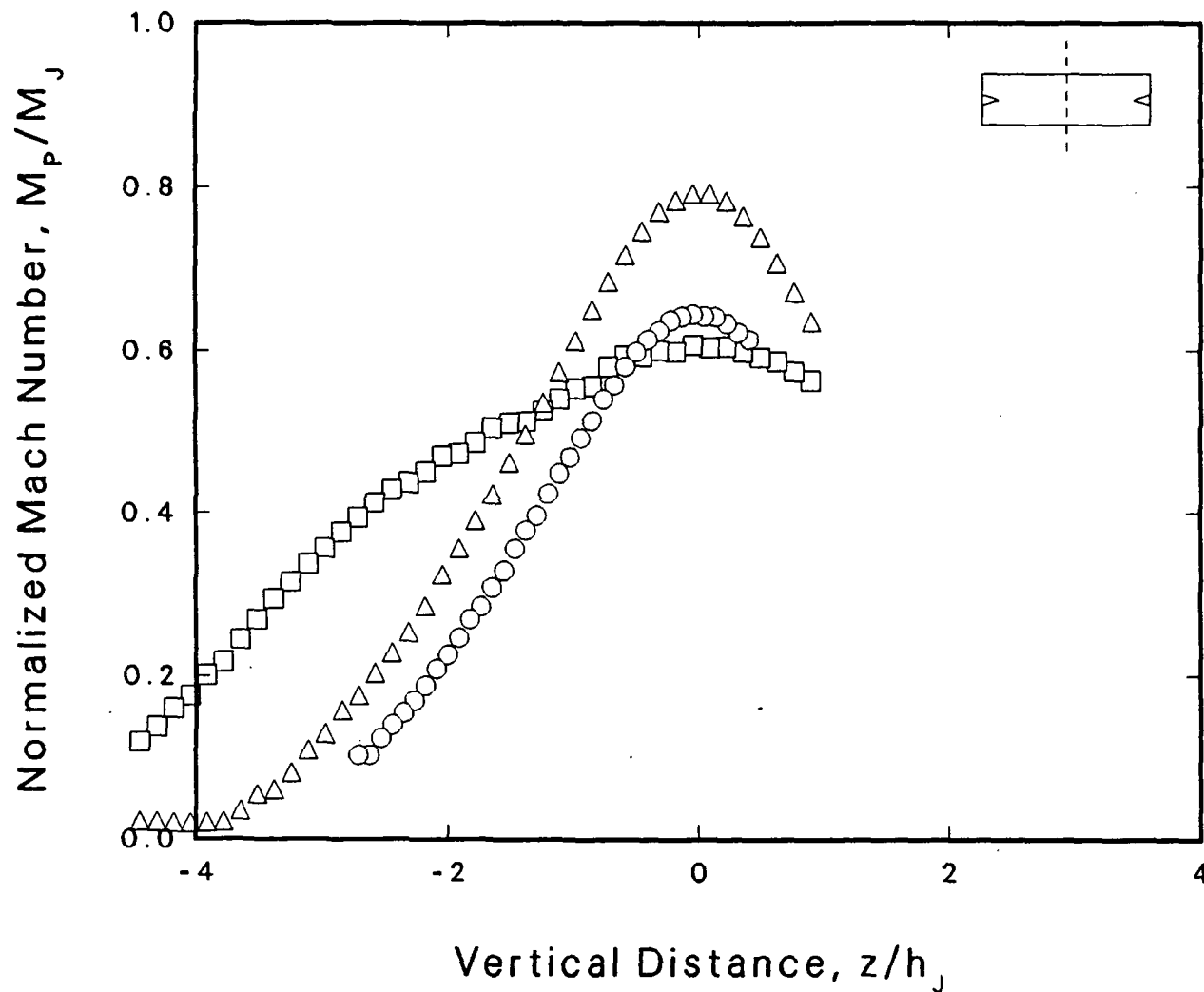
Sym	○	Δ	□
File	TAB175T	TAB177T	TAB181T
Config	0-0	III-A	III-B
M_j	0.798	0.798	0.799
T_{Tj}/T_A	1.00	1.00	1.00
T_{Tj} , K	284.2	284.1	283.9
U_j , mps	254.0	254.2	254.2
Re_{De}	1.091	1.091	1.091
Re_h	0.483	0.483	0.483
Re_w	1.991	1.990	1.990
p_A , kPa	98.476	98.307	98.138
T_A , K	285.2	285.2	283.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	-2.0

Figure B.39 Configuration III, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



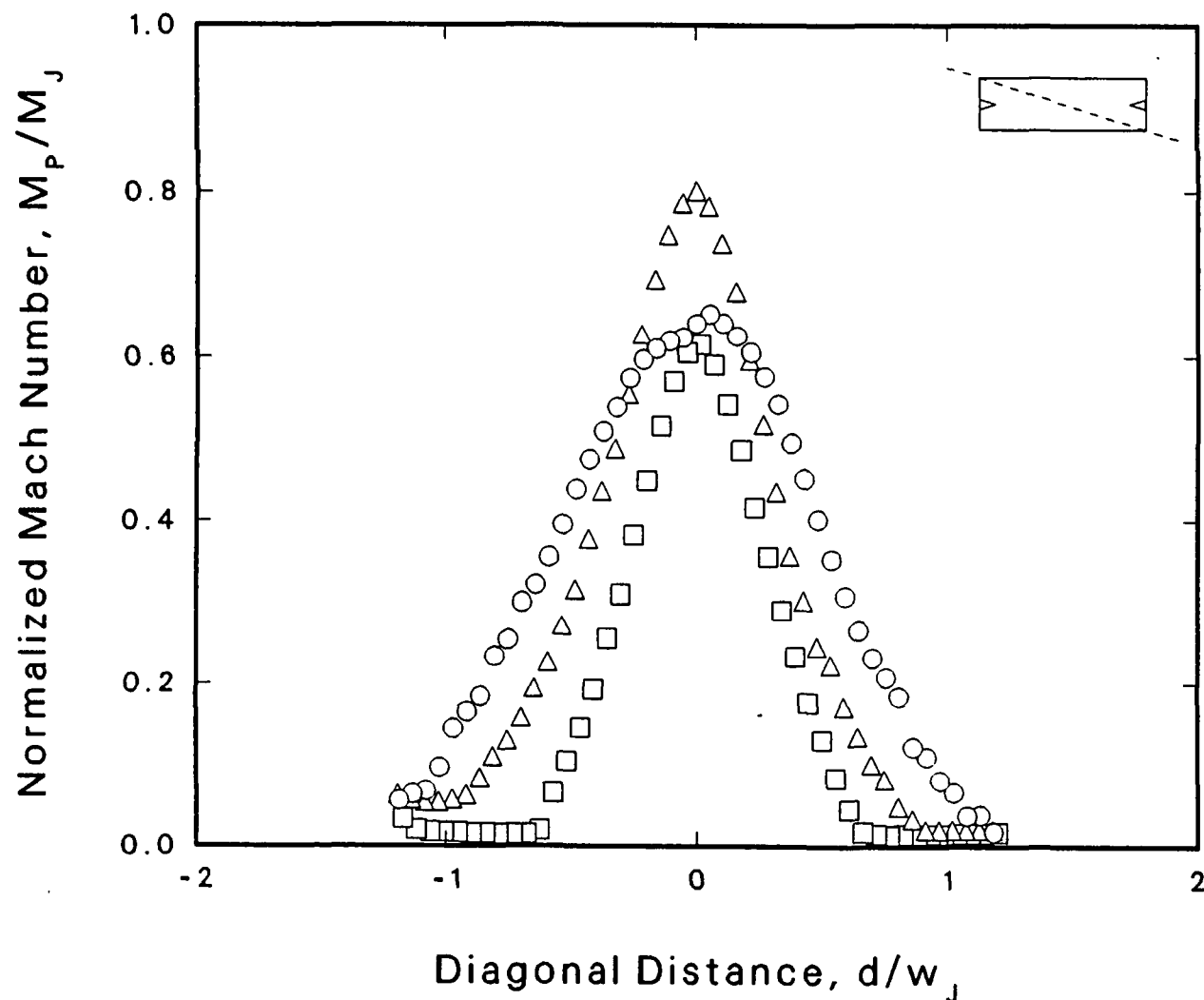
Sym	○	△	□
File	TAB147T	TAB159T	TAB151T
Config	0-0	II-B	II-A
M_j	0.800	0.797	0.798
T_{TJ}/T_A	0.97	1.00	0.97
T_{TJ}, K	285.5	284.1	285.8
U_j, mps	255.2	253.7	254.8
Re_{De}	1.087	1.090	1.080
Re_h	0.482	0.483	0.479
Re_w	1.925	1.930	1.912
p_A, kPa	98.375	98.544	98.205
T_A, K	294.6	284.9	293.8
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	-8.0	-4.0	-3.0

Figure B.40 Configuration II, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



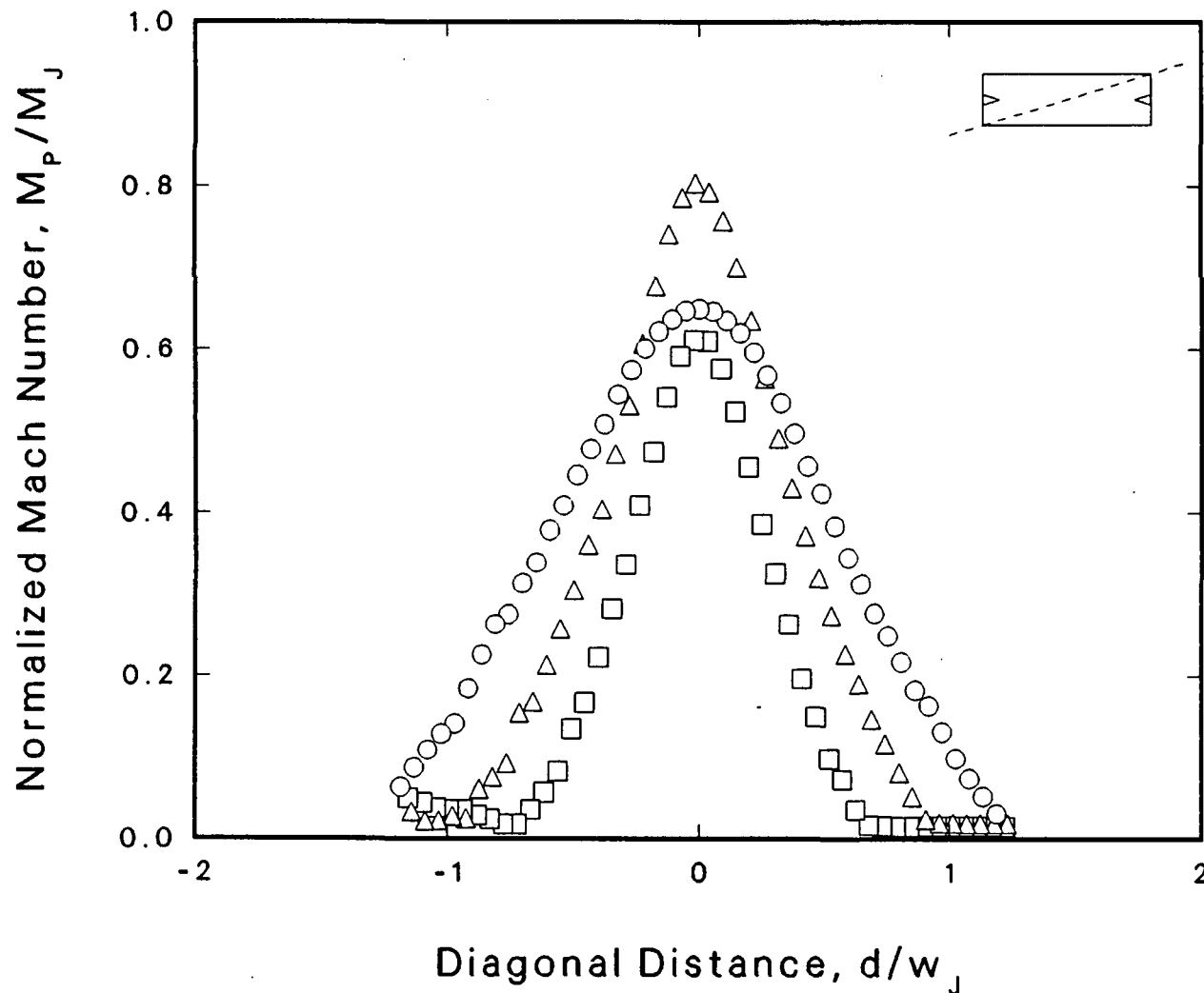
Sym	○	△	□
File	TAB146T	TAB160T	TAB152T
Config	0-0	II-B	II-A
M_j	0.800	0.796	0.797
T_{Tj}/T_A	0.97	0.99	0.98
T_{Tj}, K	285.8	284.3	285.3
U_j, mps	255.4	253.6	254.5
Re_{De}	1.086	1.089	1.082
Re_h	0.481	0.482	0.479
Re_w	1.922	1.928	1.915
p_A, kPa	98.375	98.612	98.171
T_A, K	294.9	286.0	289.7
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	1.0	0.0	0.0

Figure B.41 Configuration II, Vertical Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$



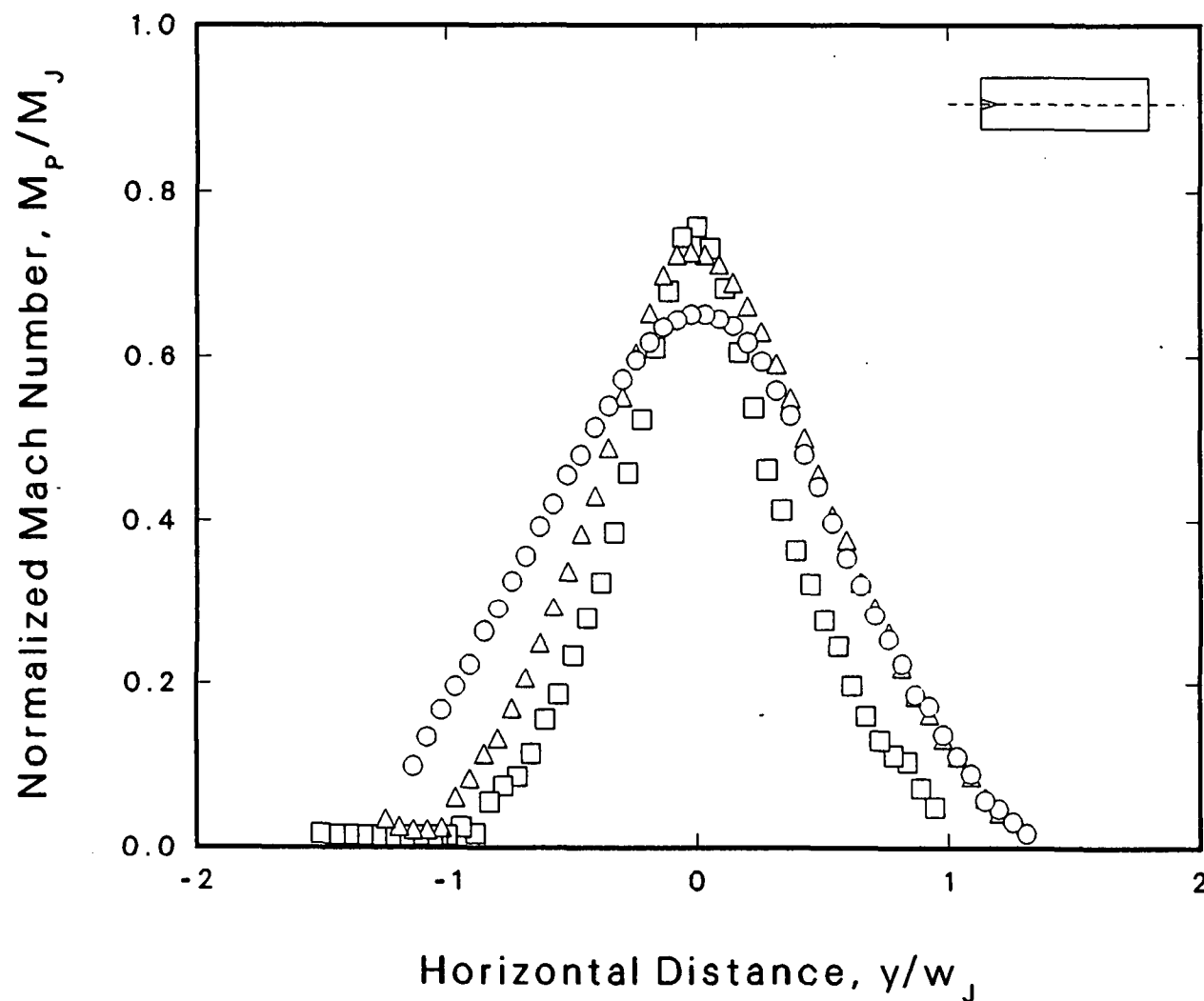
Sym	○	△	□
File	TAB165T	TAB173T	TAB171T
Config	0-0	II-B	II-A
M_J	0.797	0.797	0.799
T_{TJ}/T_A	0.98	1.01	0.98
T_{TJ} , K	285.1	283.3	284.9
U_J , mps	254.3	253.5	254.6
Re_{D_e}	1.088	1.097	1.086
Re_h	0.482	0.486	0.481
Re_w	1.985	2.001	1.982
p_A , kPa	98.713	98.679	98.205
T_A , K	290.6	279.4	289.3
De_J , mm	50.8	50.8	50.8
X/De_J	9.00	9.00	9.00
Z/h_J	0.00	0.00	0.00
ΔY , mm	0.0	0.5	-1.5

Figure B.42 Configuration II, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_J=0.8$, $T_J/T_0=1$, $\theta=-14^\circ$



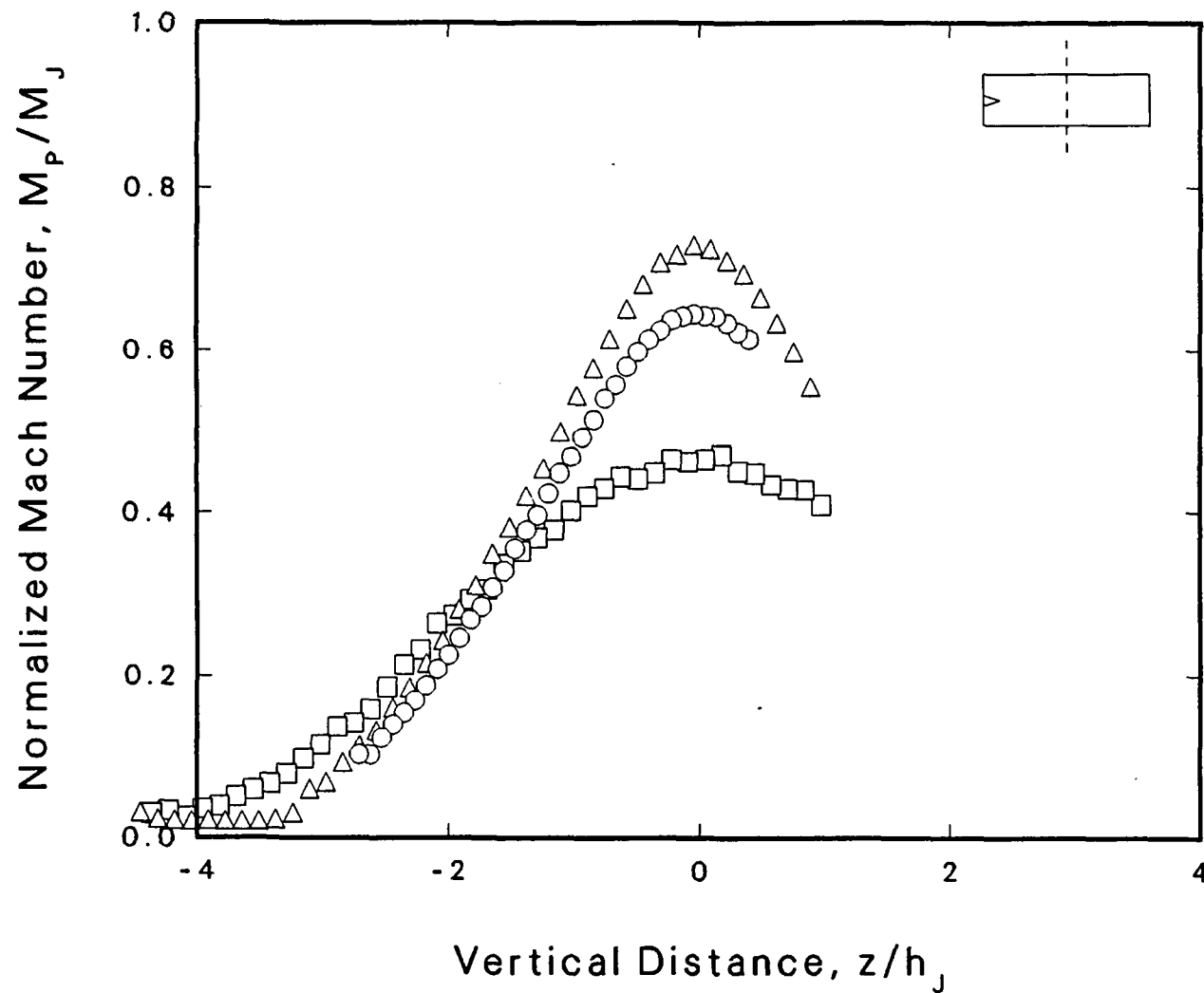
Sym	○	Δ	□
File	TAB175T	TAB182T	TAB178T
Config	0-0	II-B	II-A
M_j	0.798	0.798	0.800
T_{TJ}/T_A	1.00	0.99	1.00
T_{TJ}, K	284.2	284.2	283.6
U_j, mps	254.0	254.2	254.4
Re_{De}	1.091	1.086	1.095
Re_h	0.483	0.481	0.485
Re_w	1.991	1.982	1.997
p_A, kPa	98.476	97.968	98.138
T_A, K	285.2	285.9	282.3
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	-4.0	-3.0

Figure B.43 Configuration II, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



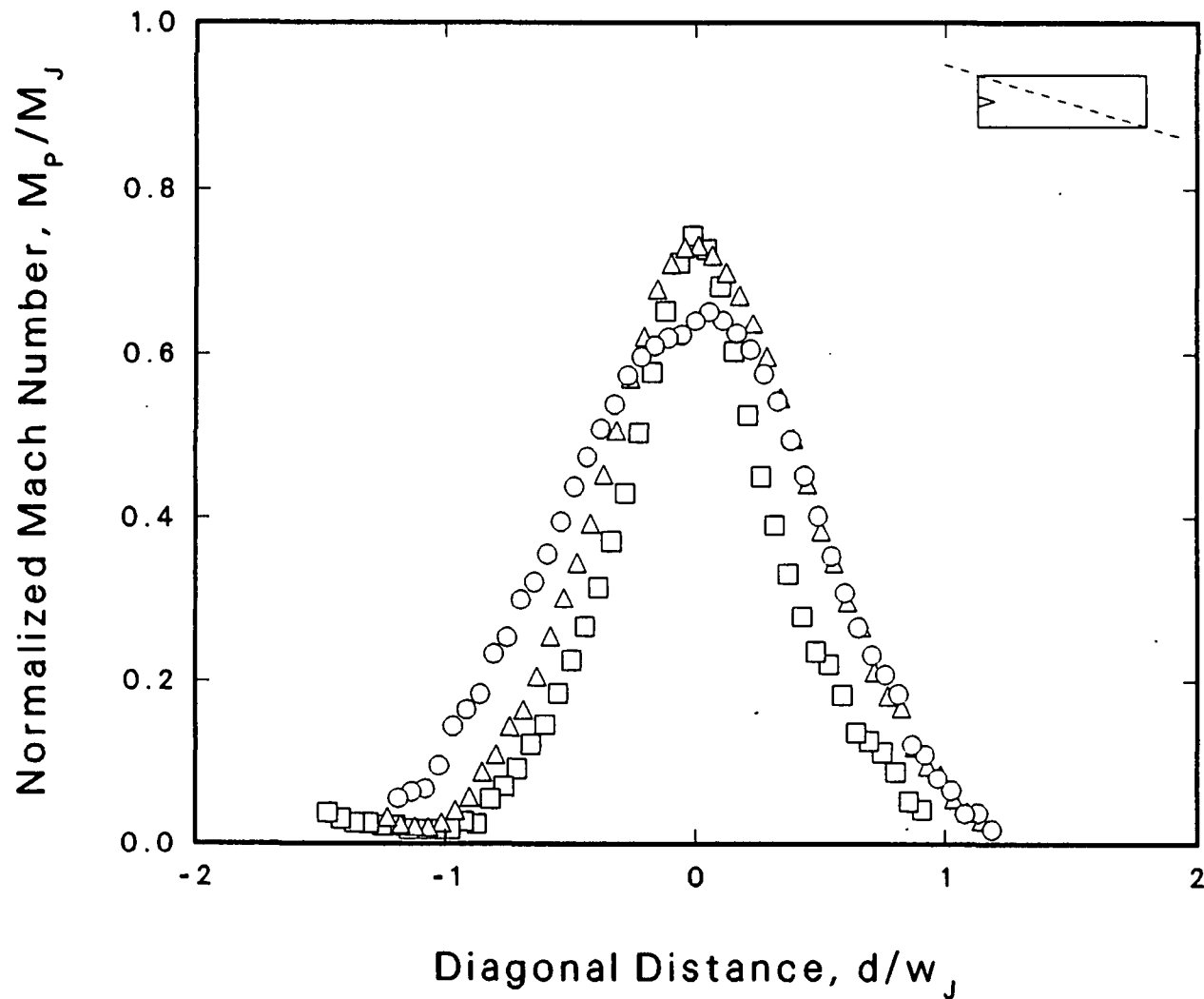
Sym	○	△	□
File	TAB147T	TAB163T	TAB153T
Config	0-0	IV-B	IV-A
M_j	0.800	0.796	0.797
T_{Tj}/T_A	0.97	0.99	0.97
T_{Tj} , K	285.5	285.0	286.4
U_j , mps	255.2	254.0	254.9
Re_{D_e}	1.087	1.085	1.075
Re_h	0.482	0.480	0.476
Re_w	1.925	1.920	1.902
p_A , kPa	98.375	98.476	98.070
T_A , K	294.6	289.1	294.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	-8.0	2.0	25.0

Figure B.44 Configuration IV, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



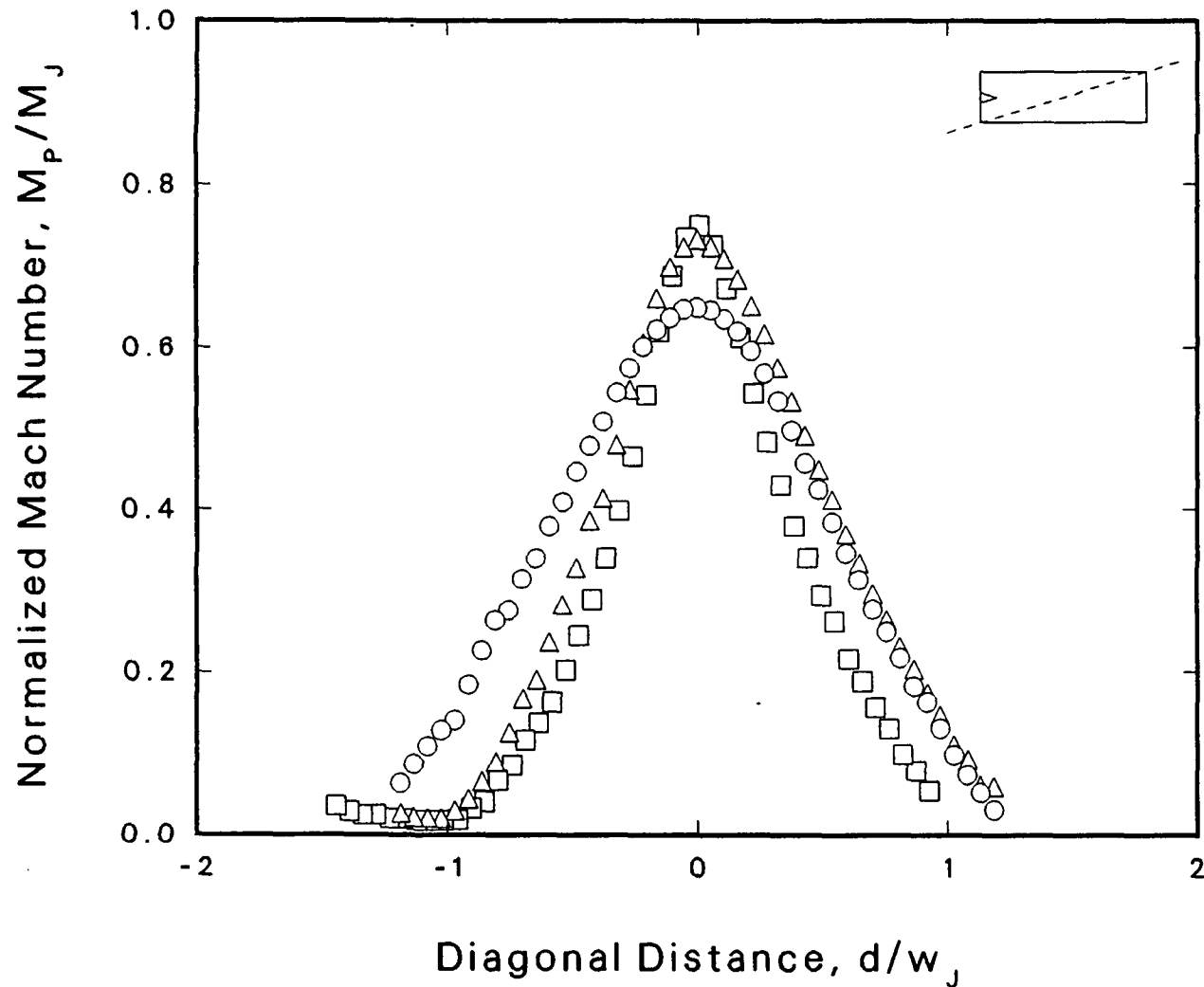
Sym	O	Δ	□
File	TAB146T	TAB164T	TAB154T
Config	0-0	IV-B	IV-A
M_j	0.800	0.802	0.802
T_{Tj}/T_A	0.97	0.99	0.97
T_{Tj}, K	285.8	284.7	286.8
U_j, mps	255.4	255.4	256.3
Re_{D_e}	1.086	1.095	1.079
Re_h	0.481	0.485	0.478
Re_w	1.922	1.939	1.910
p_A, kPa	98.375	98.476	97.901
T_A, K	294.9	288.3	296.5
D_{e_j}, mm	50.8	50.8	50.8
X/D_{e_j}	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	1.0	0.0	-2.0

Figure B.45 Configuration IV, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



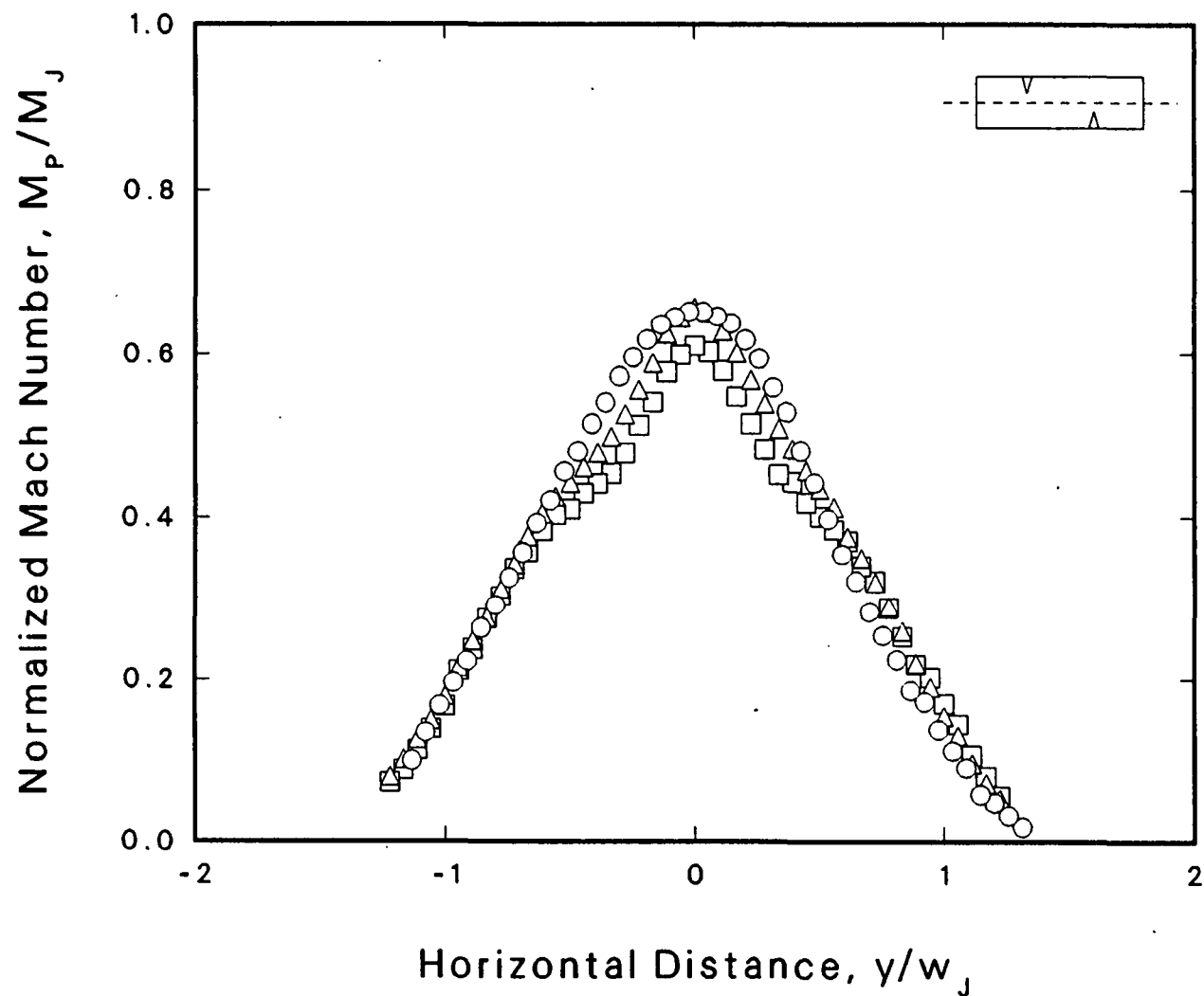
Sym	○	△	□
File	TAB165T	TAB174T	TAB172T
Config	0-0	IV-B	IV-A
M_j	0.797	0.798	0.798
T_{TJ}/T_A	0.98	1.01	0.99
T_{TJ} , K	285.1	283.5	284.5
U_j , mps	254.3	253.8	254.3
Re_{De}	1.088	1.098	1.087
Re_h	0.482	0.486	0.481
Re_w	1.985	2.003	1.983
p_A , kPa	98.713	98.679	98.171
T_A , K	290.6	280.3	288.1
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	4.0	26.0

Figure B.46 Configuration IV, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$



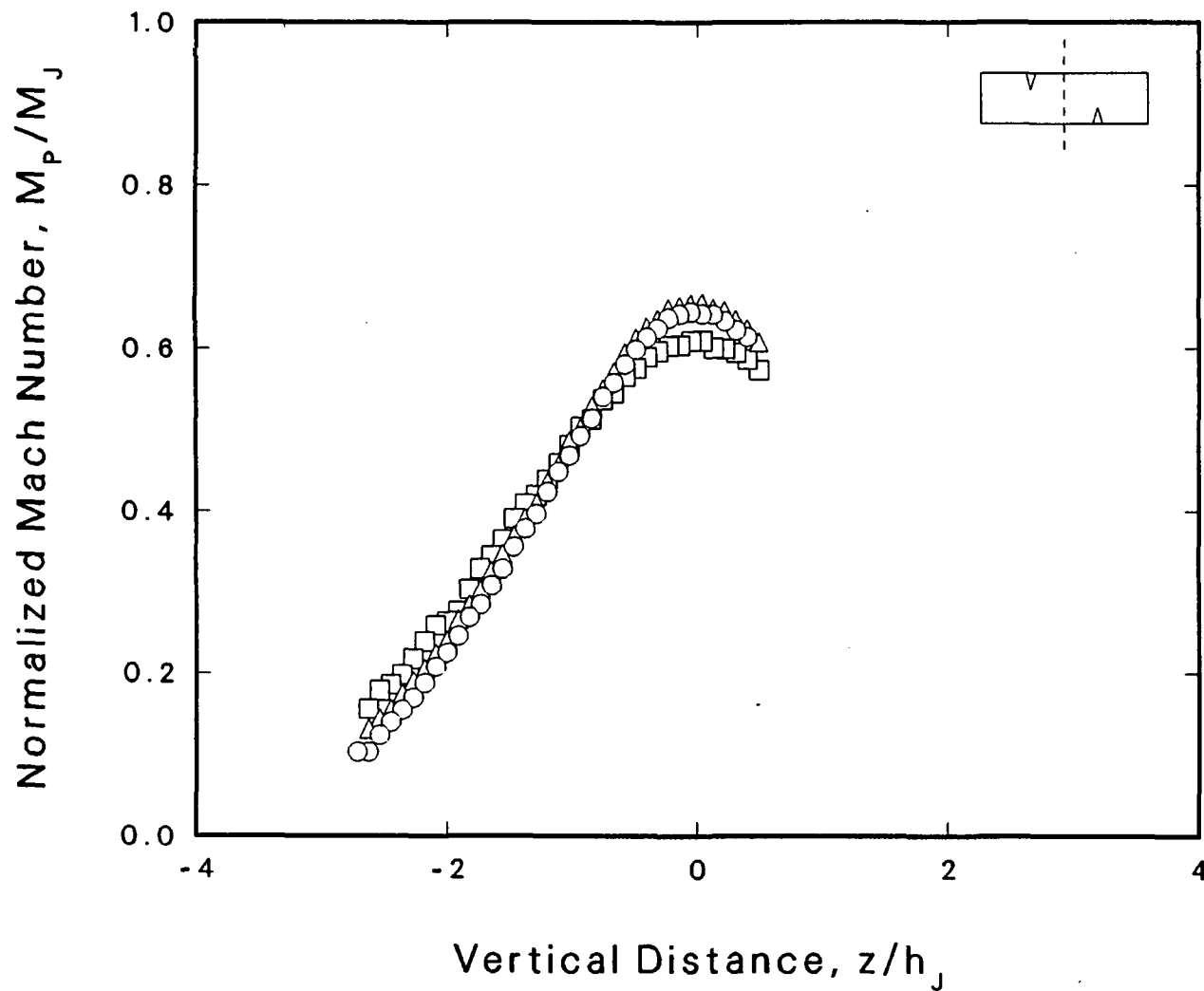
Sym	○	△	□
File	TAB175T	TAB183T	TAB179T
Config	0-0	IV-B	IV-A
M_j	0.798	0.798	0.800
T_{TJ}/T_A	1.00	0.99	1.01
T_{TJ} , K	284.2	284.3	283.8
U_j , mps	254.0	254.2	254.4
Re_{De}	1.091	1.085	1.093
Re_h	0.483	0.480	0.484
Re_w	1.991	1.979	1.993
p_A , kPa	98.476	97.867	98.138
T_A , K	285.2	286.3	282.2
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	24.0

Figure B.47 Configuration IV, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



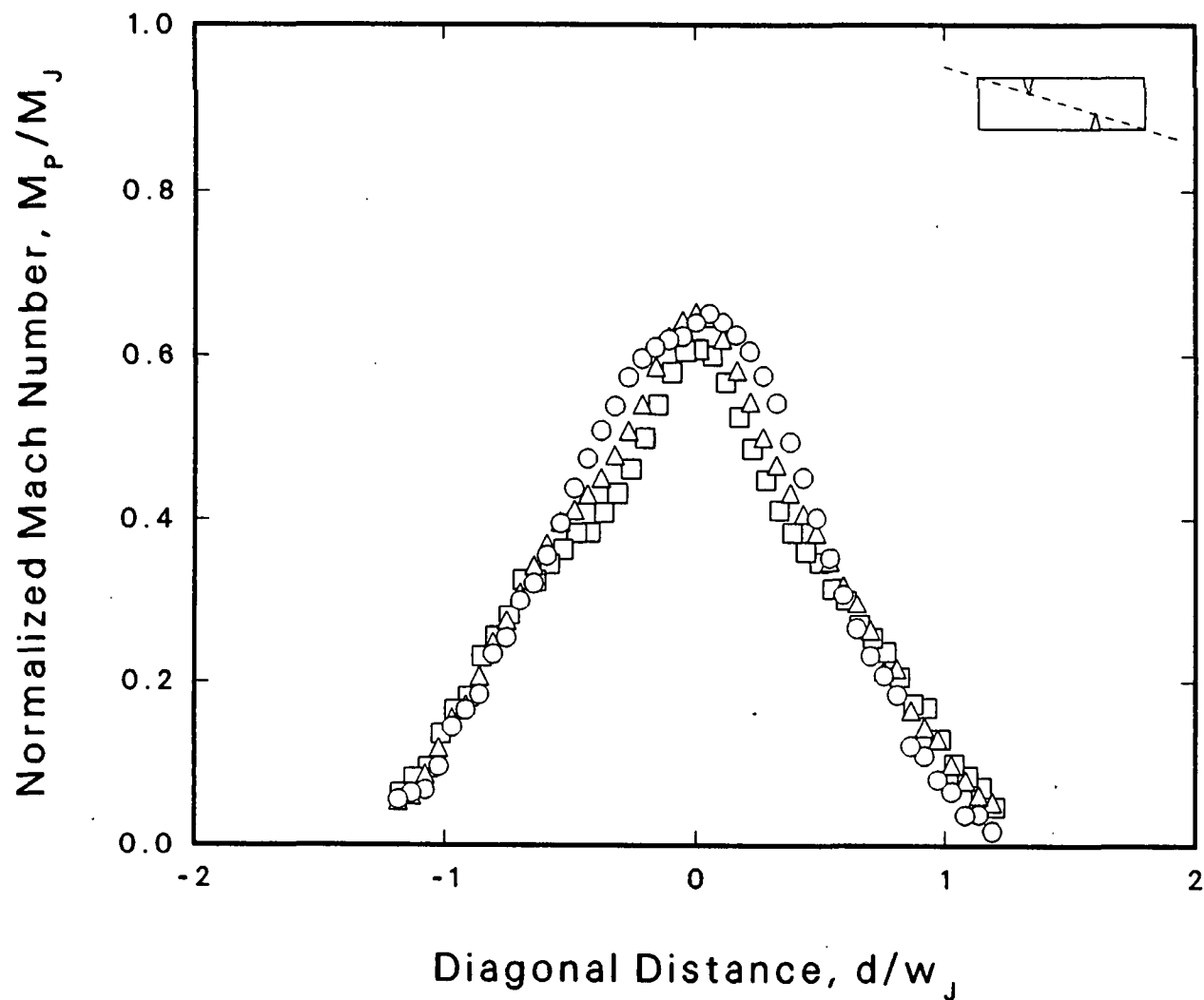
Sym	○	Δ	□
File	TAB147T	TAB242T	TAB252T
Config	0-0	VI-A	VI-B
M_j	0.800	0.798	0.796
T_{TJ}/T_A	0.97	0.99	1.01
T_{TJ} , K	285.5	280.6	279.0
U_j , mps	255.2	252.5	251.2
Re_{De}	1.087	1.100	1.114
Re_h	0.482	0.487	0.493
Re_w	1.925	1.947	1.972
p_A , kPa	98.375	97.562	98.408
T_A , K	294.6	282.1	277.1
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	-8.0	0.0	0.0

Figure B.48 Configuration VI, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



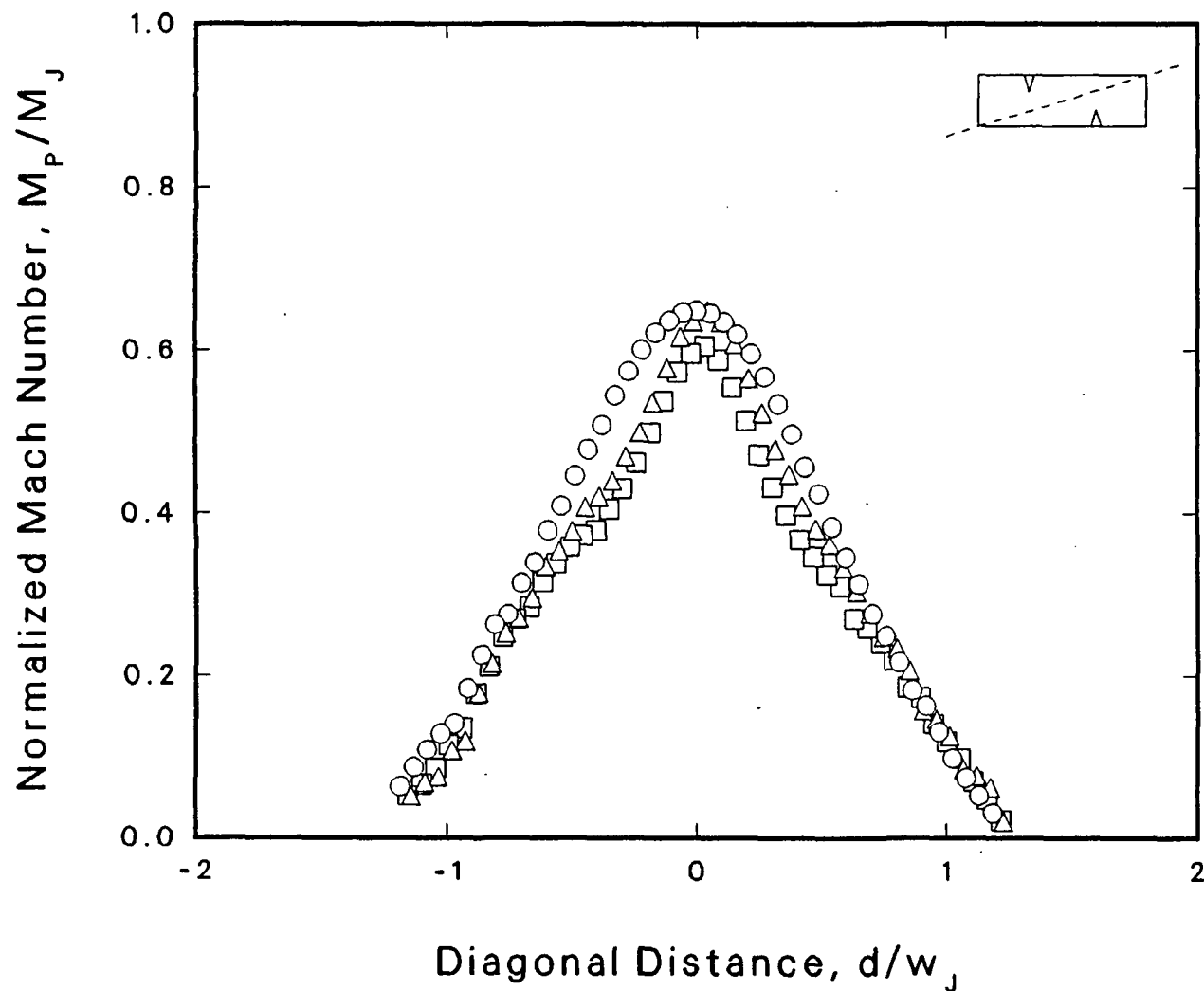
Sym	○	Δ	□
File	TAB146T	TAB241T	TAB263T
Config	0-0	VI-A	VI-B
M_j	0.800	0.798	0.796
T_{Tj}/T_A	0.97	0.98	1.00
T_{Tj}, K	285.8	281.0	279.1
U_j, mps	255.4	252.7	251.3
Re_{D_o}	1.086	1.103	1.114
Re_h	0.481	0.489	0.494
Re_w	1.922	1.953	1.973
p_A, kPa	98.375	98.104	98.476
T_A, K	294.9	287.0	278.0
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	1.0	-1.0	-1.0

Figure B.49 Configuration VI, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



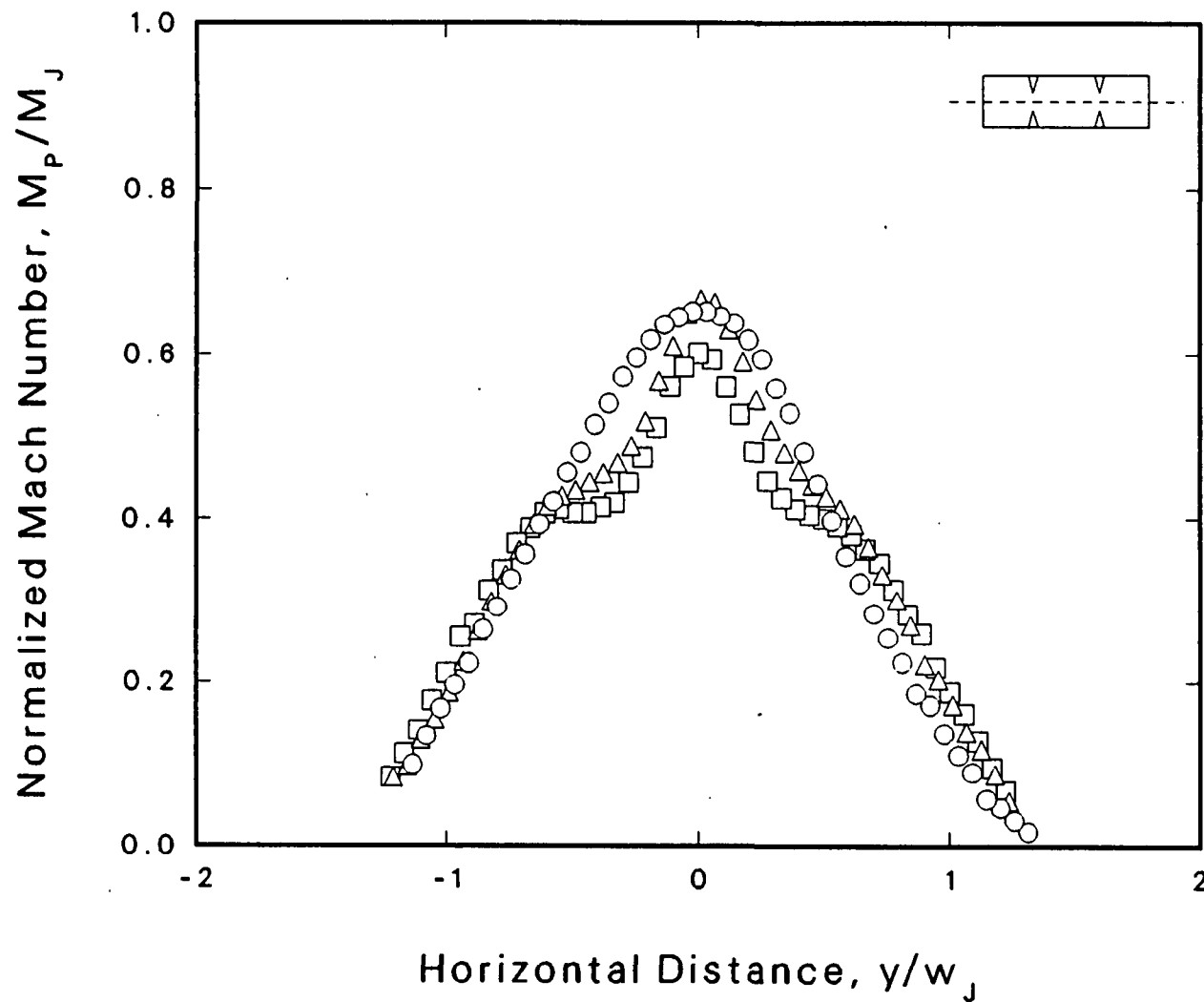
Sym	○	Δ	□
File	TAB165T	TAB257T	TAB264T
Config	0-0	VI-A	VI-B
M_j	0.797	0.797	0.797
T_{TJ}/T_A	0.98	0.99	1.01
T_{TJ} , K	285.1	281.0	278.9
U_j , mps	254.3	252.5	251.4
Re_{De}	1.088	1.106	1.119
Re_h	0.482	0.490	0.495
Re_w	1.985	2.018	2.041
p_A , kPa	98.713	98.476	98.612
T_A , K	290.6	283.9	276.4
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	-1.0

Figure B.50 Configuration VI, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$



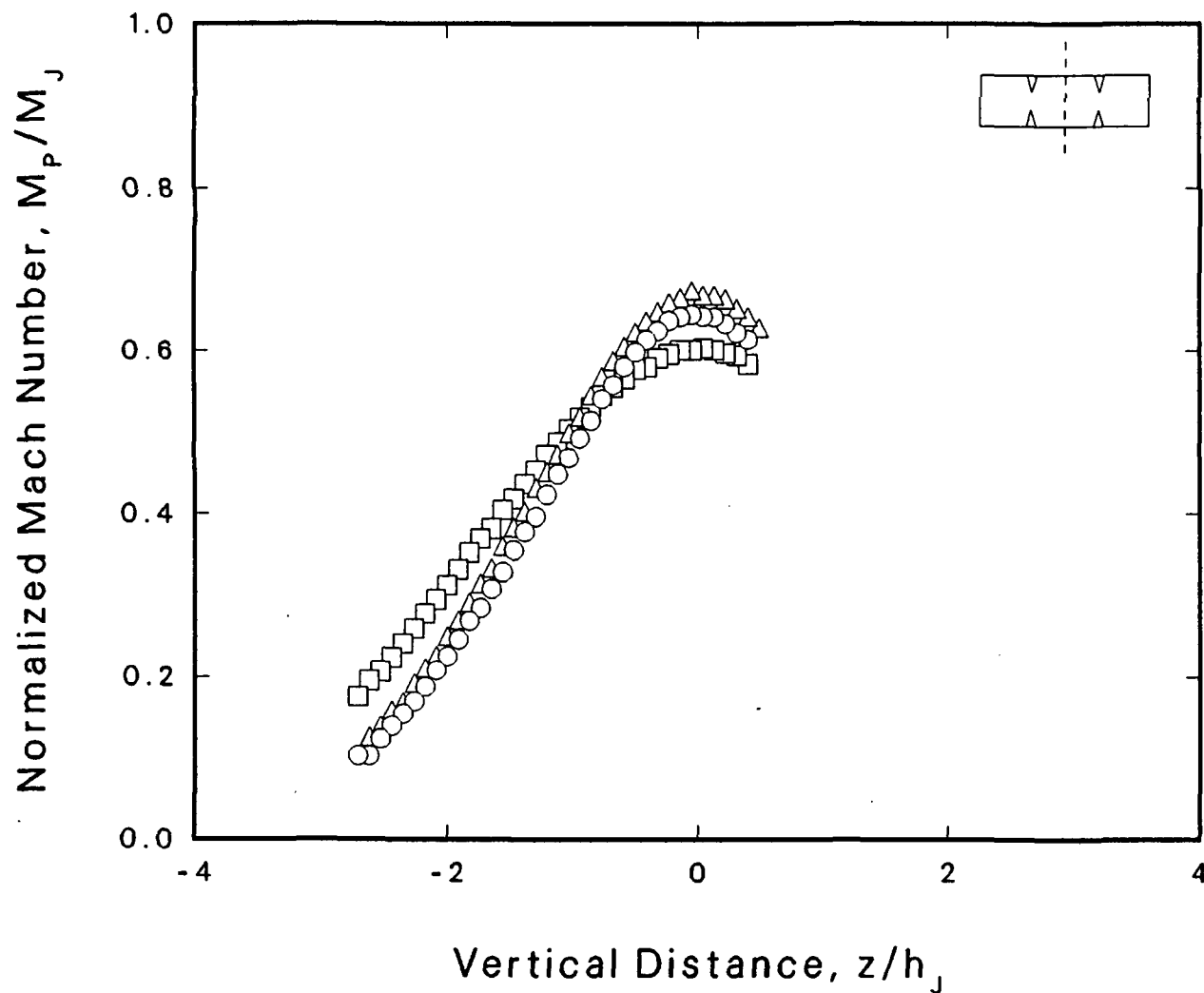
Sym	○	Δ	□
File	TAB175T	TAB269T	TAB273T
Config	0-0	VI-A	VI-B
M_j	0.798	0.798	0.797
T_{TJ}/T_A	1.00	0.97	0.99
T_{TJ} , K	284.2	281.0	279.9
U_j , mps	254.0	252.6	252.0
Re_{D_e}	1.091	1.106	1.114
Re_h	0.483	0.490	0.493
Re_w	1.991	2.018	2.032
p_A , kPa	98.476	98.375	98.612
T_A , K	285.2	289.8	283.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	-4.0	-3.0

Figure B.51 Configuration VI, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



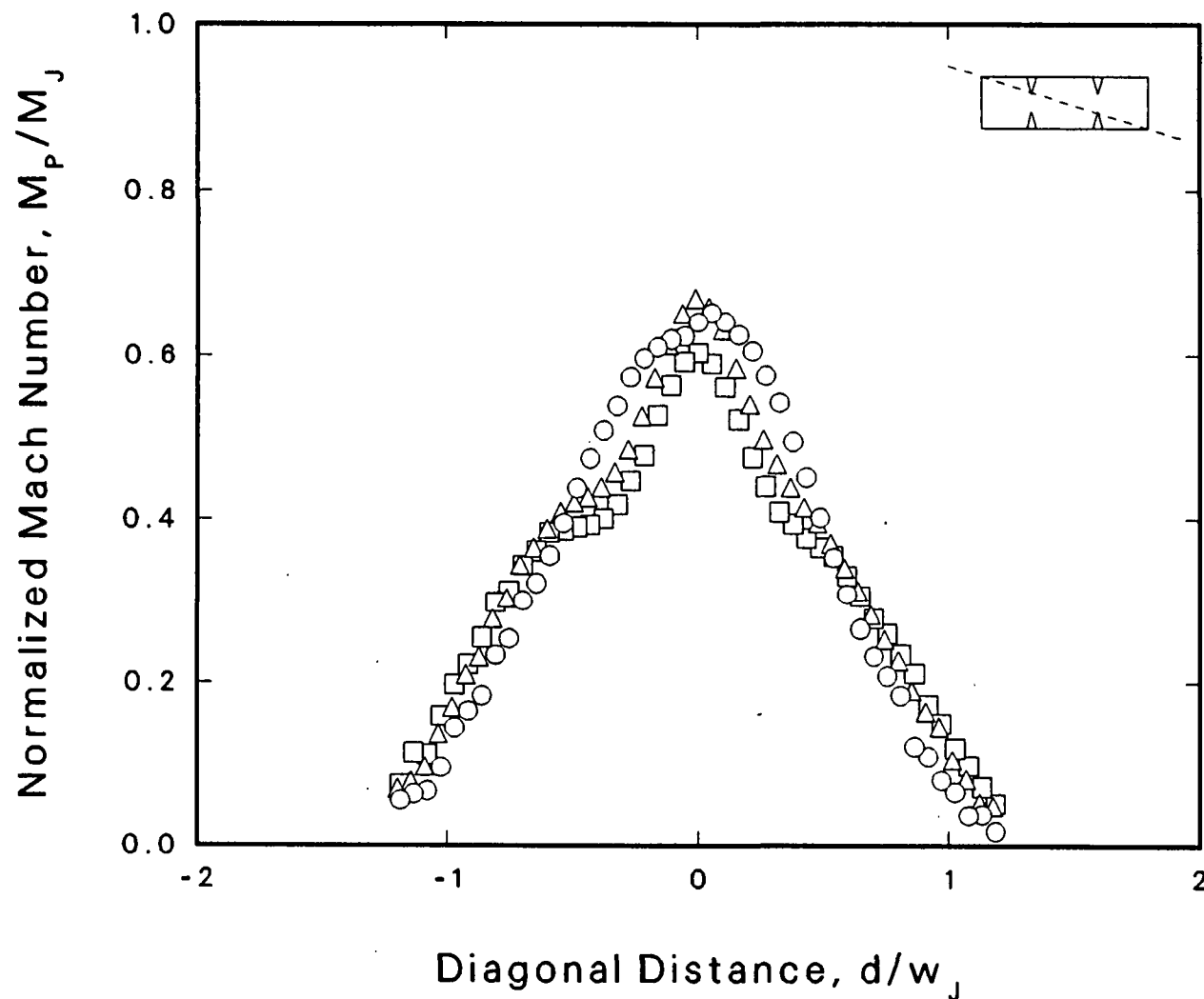
Sym	○	Δ	□
File	TAB147T	TAB239T	TAB248T
Config	0-0	VII-A	VII-B
M_j	0.800	0.796	0.799
T_{Tj}/T_A	0.97	0.98	0.98
T_{Tj}, K	285.5	281.0	280.9
U_j, mps	255.2	252.2	252.8
Re_{De}	1.087	1.101	1.094
Re_h	0.482	0.488	0.485
Re_w	1.925	1.950	1.937
p_A, kPa	98.375	98.171	97.156
T_A, K	294.6	286.8	286.7
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	-8.0	-1.0	0.0

Figure B.52 Configuration VII, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$



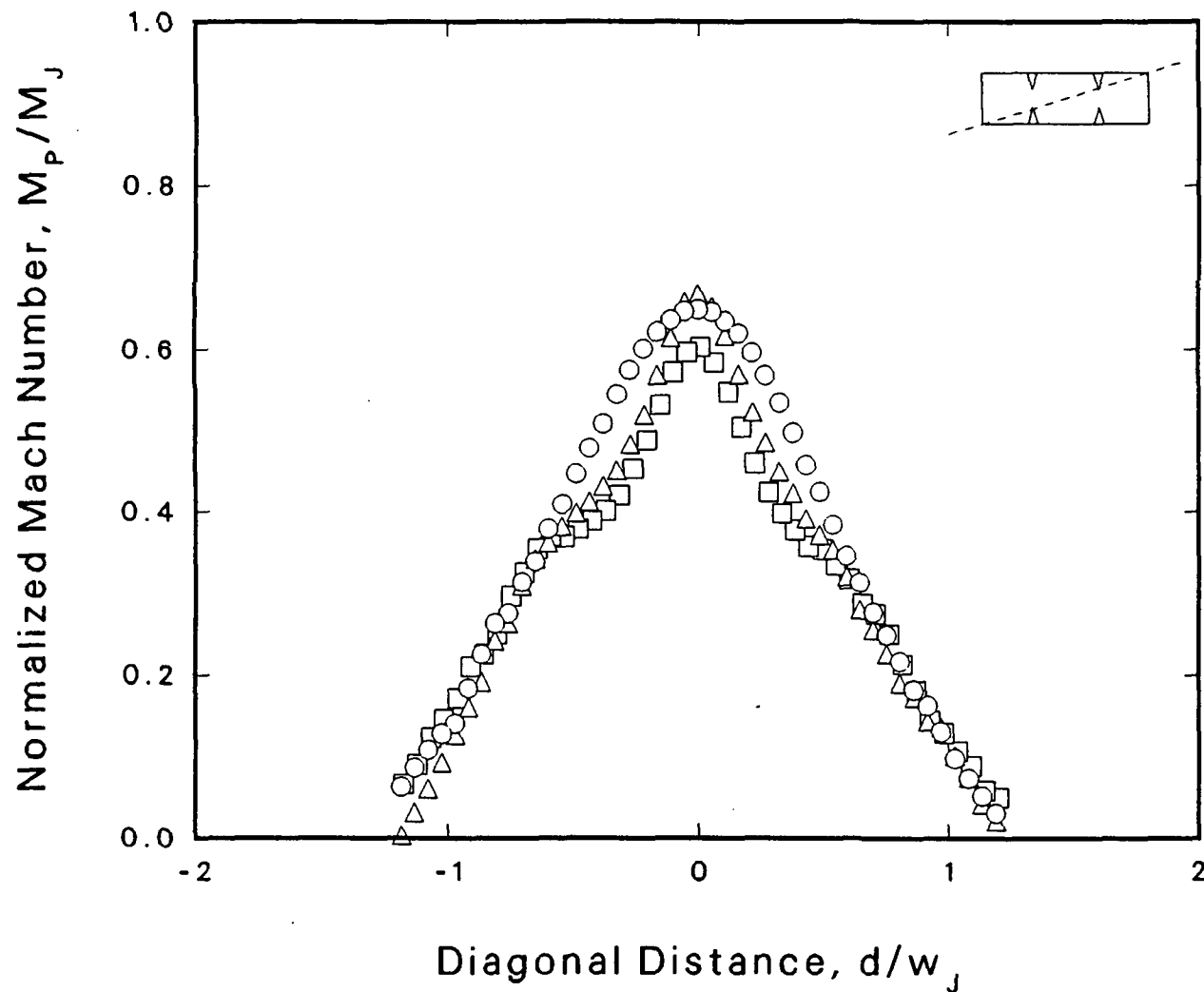
Sym	○	Δ	□
File	TAB146T	TAB240T	TAB249T
Config	0-0	VII-A	VII-B
M_j	0.800	0.798	0.798
T_{TJ}/T_A	0.97	0.98	0.98
T_{TJ} , K	285.8	281.1	281.0
U_j , mps	255.4	252.6	252.7
Re_{De}	1.086	1.103	1.094
Re_h	0.481	0.488	0.484
Re_w	1.922	1.952	1.936
p_A , kPa	98.375	98.104	97.189
T_A , K	294.9	287.0	286.9
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	1.0	-1.0	1.0

Figure B.53 Configuration VII, Vertical Mach Number Profile,
 $X/De_j=9$, $M_j=0.8$, $T_j/T_0=1$



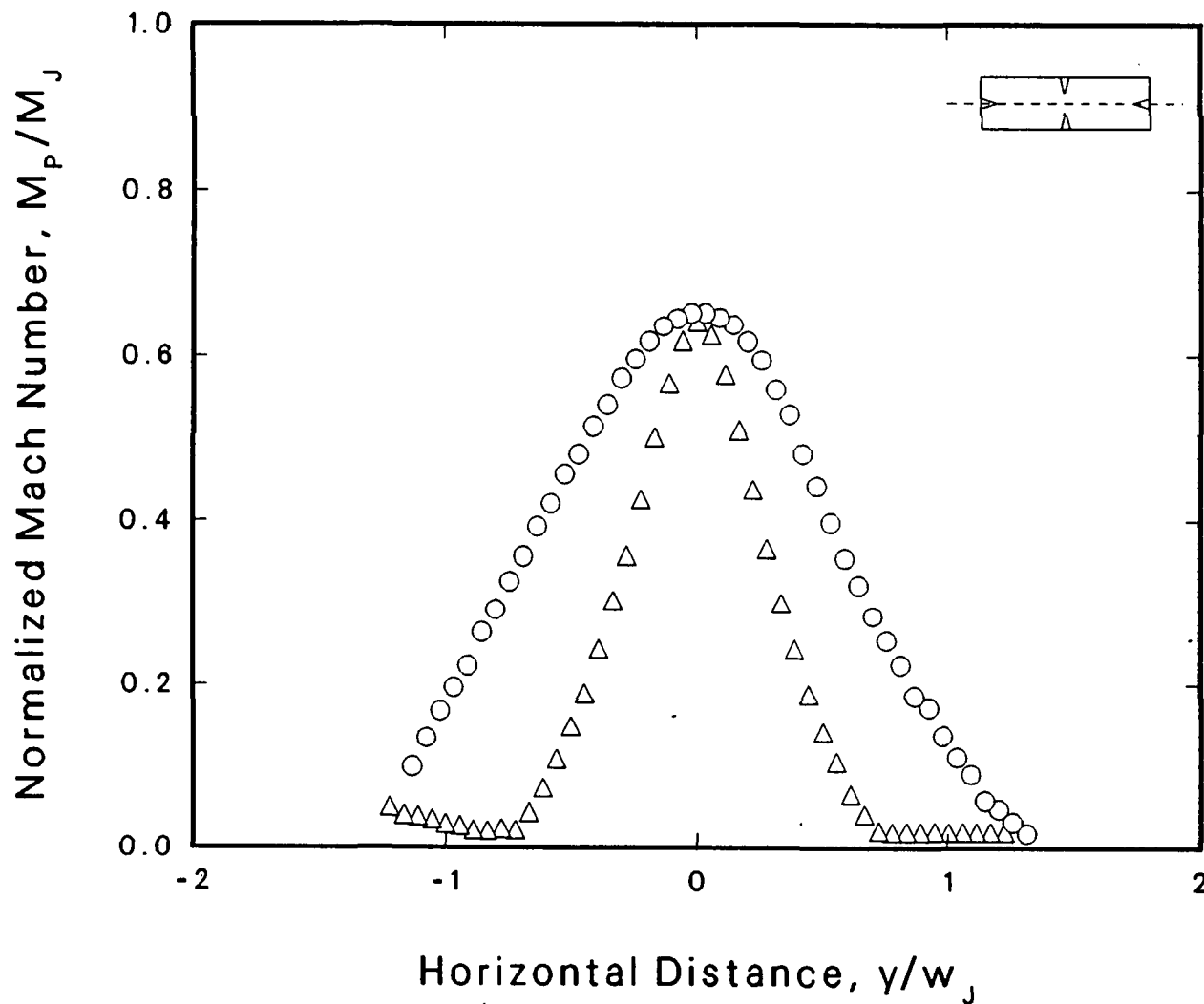
Sym	○	Δ	□
File	TAB165T	TAB256T	TAB261T
Config	0-0	VII-A	VII-B
M_j	0.797	0.798	0.797
T_{Tj}/T_A	0.98	0.99	0.99
T_{Tj} , K	285.1	281.1	280.4
U_j , mps	254.3	252.6	252.2
Re_{D_o}	1.088	1.106	1.114
Re_h	0.482	0.490	0.493
Re_w	1.985	2.019	2.032
p_A , kPa	98.713	98.442	98.883
T_A , K	290.6	284.1	281.9
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	1.0	0.0

Figure B.54 Configuration VII, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$



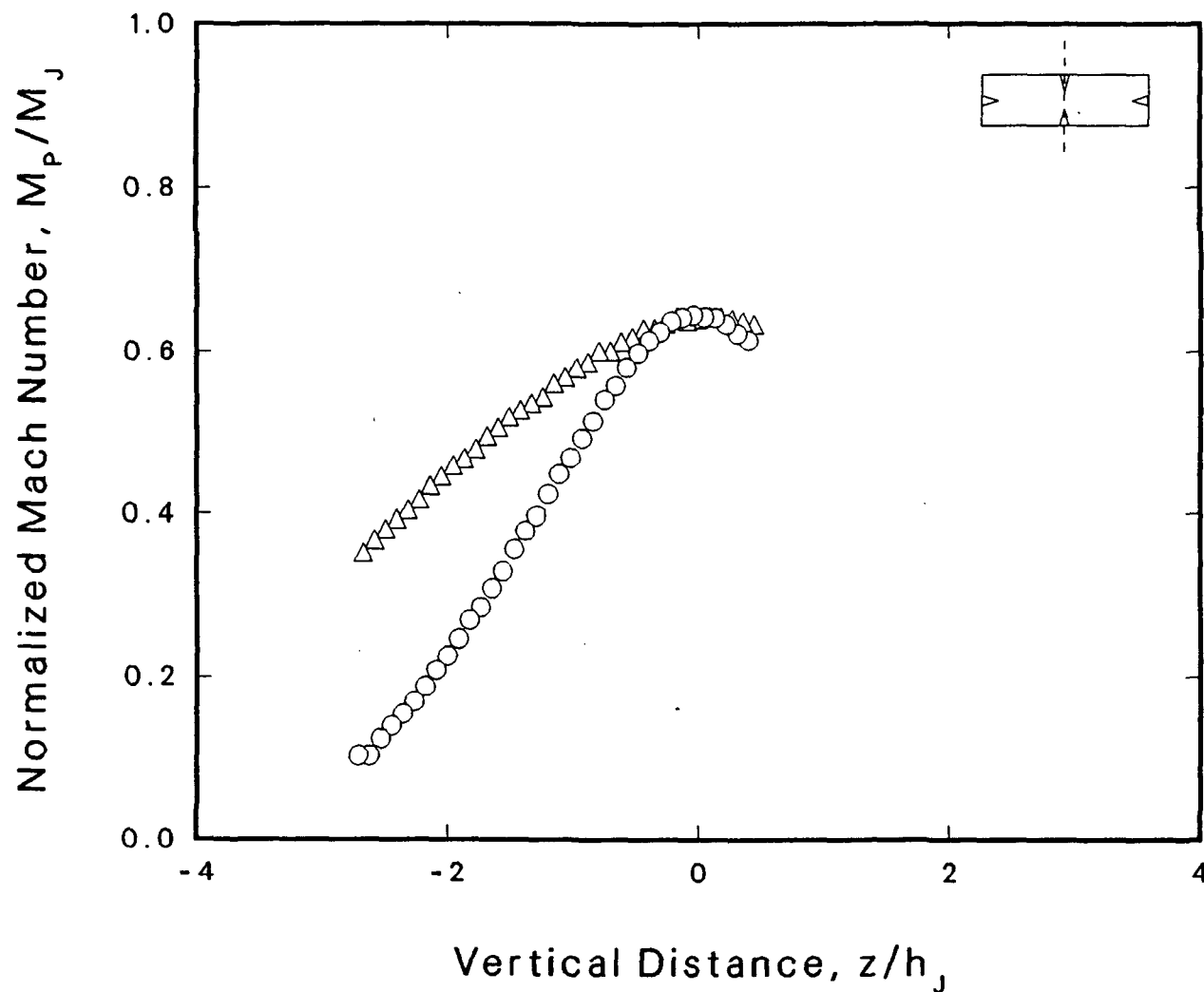
Sym	○	△	□
File	TAB175T	TAB268T	TAB272T
Config	0-0	VII-A	VII-B
M_j	0.798	0.796	0.797
T_{TJ}/T_A	1.00	1.00	0.99
T_{TJ} , K	284.2	278.1	279.7
U_j , mps	254.0	250.9	251.9
Re_{De}	1.091	1.124	1.115
Re_h	0.483	0.498	0.494
Re_w	1.991	2.051	2.034
p_A , kPa	98.476	98.815	98.578
T_A , K	285.2	277.5	282.2
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	-1.0

Figure B.55 Configuration VII, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



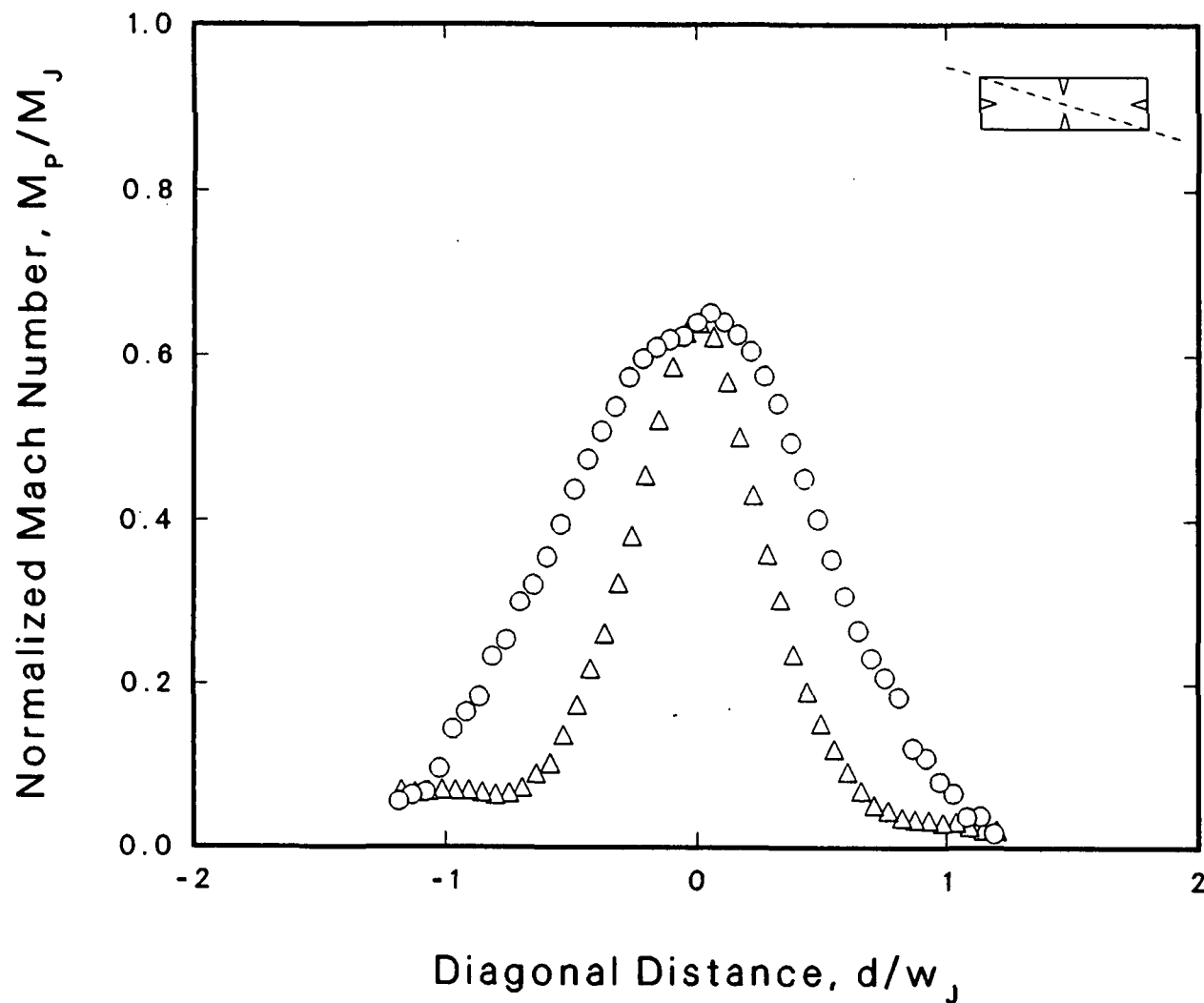
Sym	O	Δ
File	TAB147T	TAB275T
Config	0-0	V-C
M_j	0.800	0.798
T_{TJ}/T_A	0.97	0.98
T_{TJ}, K	285.5	280.0
U_j, mps	255.2	252.4
Re_{De}	1.087	1.113
Re_h	0.482	0.493
Re_w	1.925	1.970
p_A, kPa	98.375	98.408
T_A, K	294.6	285.6
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	-8.0	0.0

Figure B.56 Configuration V-C, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$



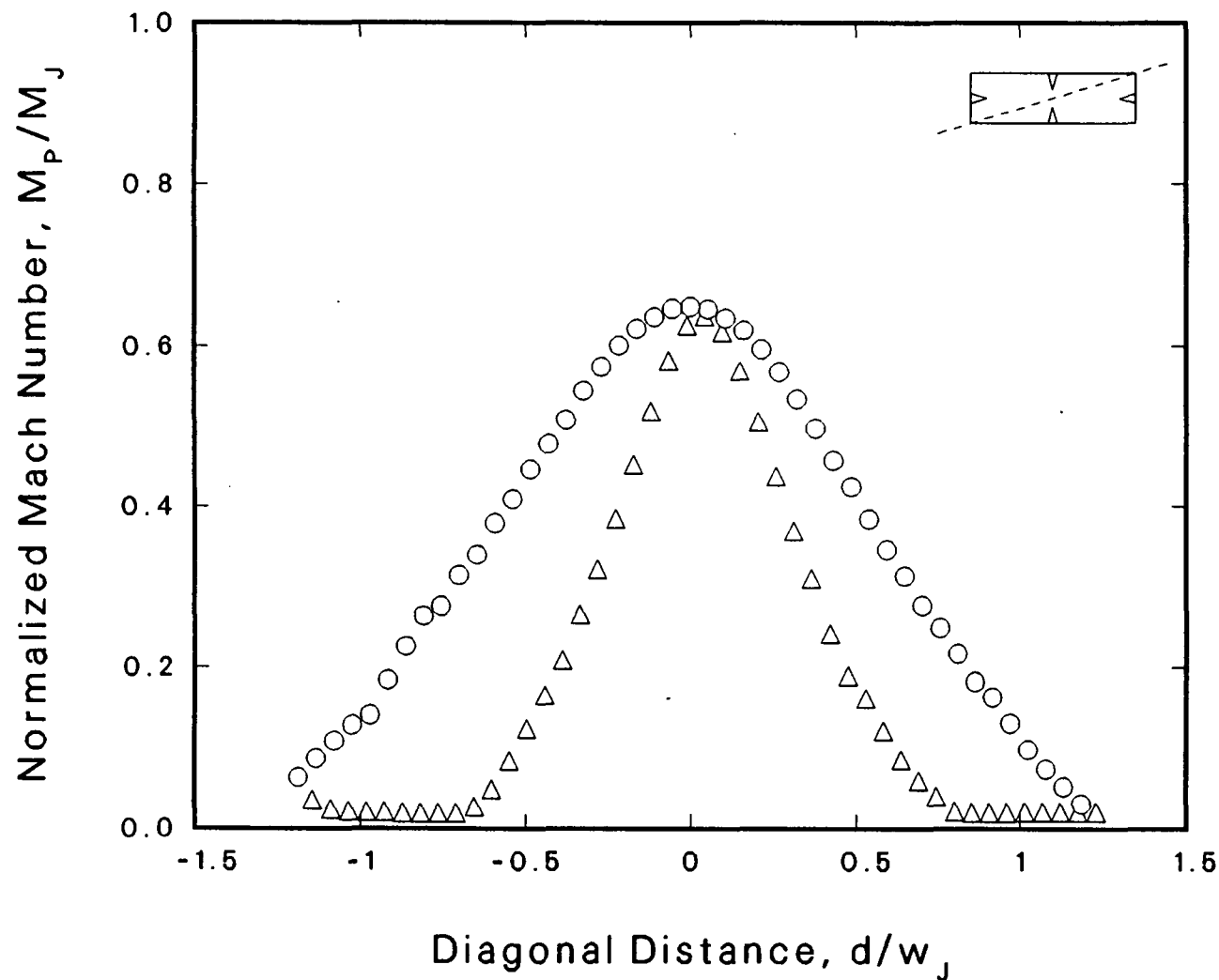
Sym	O	Δ
File	TAB146T	TAB276T
Config	0-0	V-C
M_j	0.800	0.799
T_{TJ}/T_A	0.97	0.98
T_{TJ} , K	285.8	279.8
U_j , mps	255.4	252.5
Re_{De}	1.086	1.115
Re_h	0.481	0.494
Re_w	1.922	1.974
p_A , kPa	98.375	98.341
T_A , K	294.9	284.6
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	1.0	0.0

Figure B.57 Configuration V-C, Vertical Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$



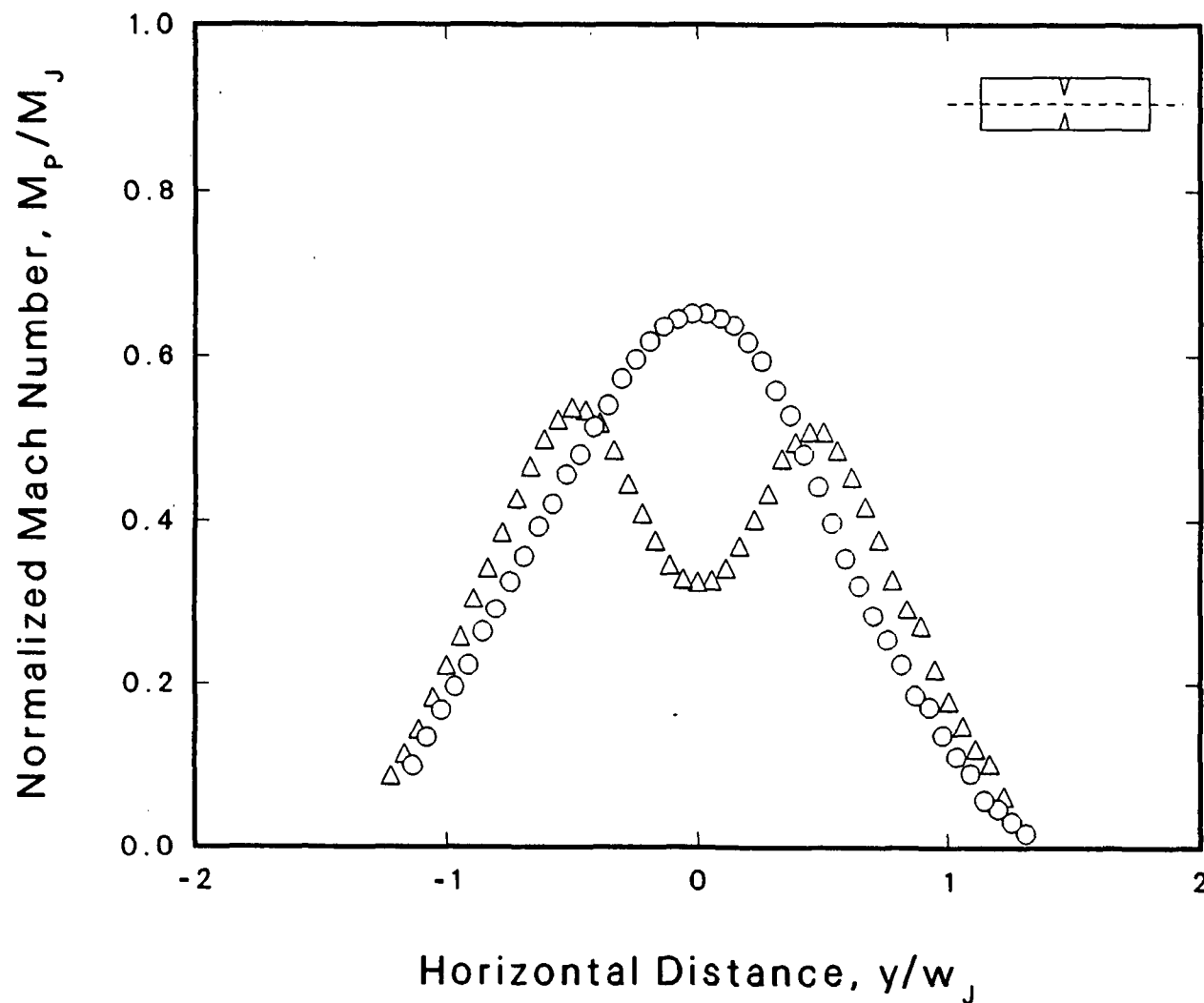
Sym	O	Δ
File	TAB165T	TAB260T
Config	0-0	V-C
M_j	0.797	0.797
T_{Tj}/T_A	0.98	1.00
T_{Tj} , K	285.1	279.5
U_j , mps	254.3	251.9
Re_{De}	1.088	1.119
Re_h	0.482	0.496
Re_w	1.985	2.041
p_A , kPa	98.713	98.815
T_A , K	290.6	278.4
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	0.0	-1.0

Figure B.58 Configuration V-C, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$



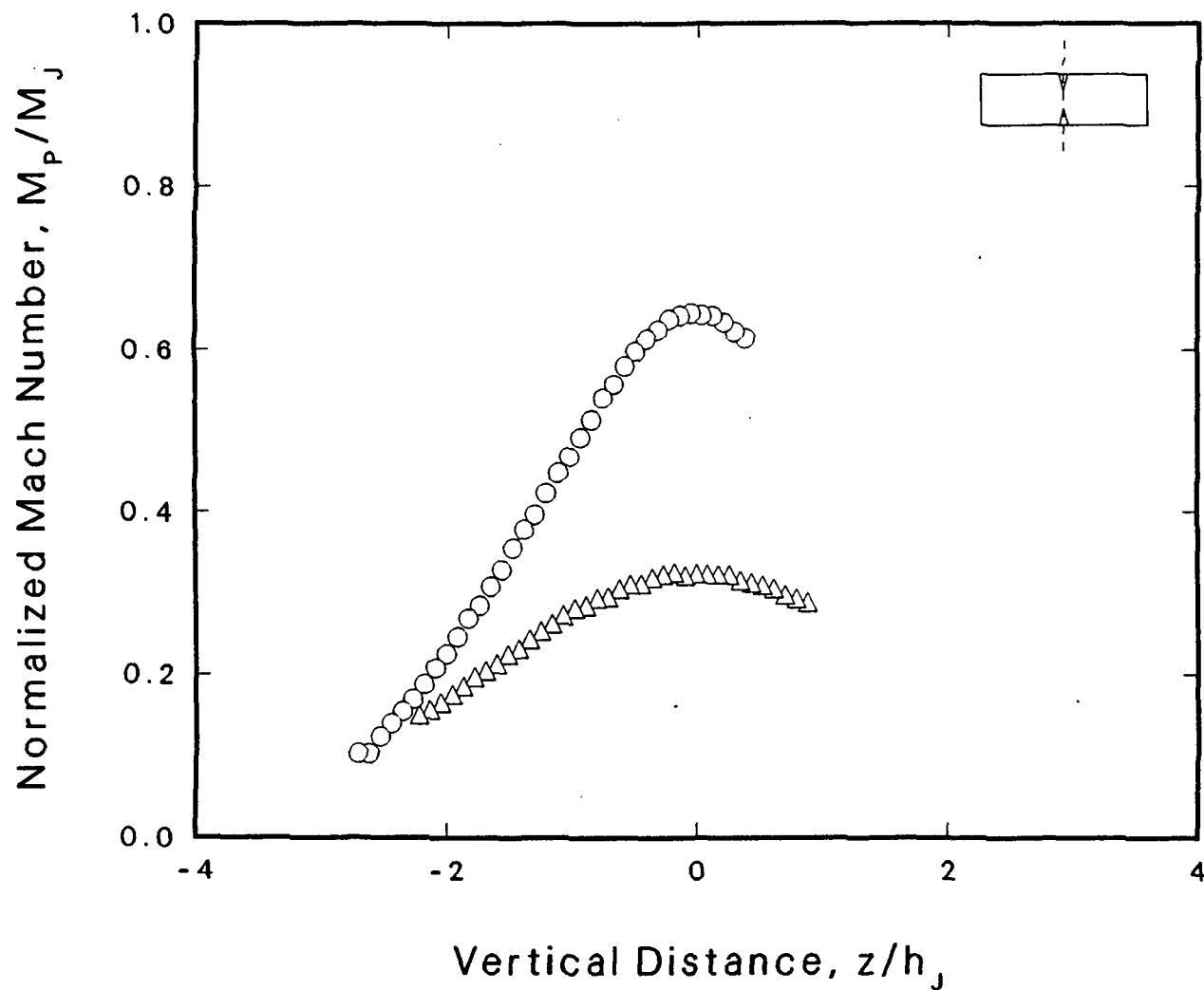
Sym	O	Δ
File	TAB175T	TAB274T
Config	0-0	V-C
M_j	0.798	0.798
T_{TJ}/T_A	1.00	0.98
T_{TJ}, K	284.2	280.3
U_j, mps	254.0	252.3
Re_{De}	1.091	1.111
Re_h	0.483	0.492
Re_w	1.991	2.027
p_A, kPa	98.476	98.442
T_A, K	285.2	286.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-4.0

Figure B.59 Configuration V-C, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$, $\theta=14^\circ$



Sym	O	Δ
File	TAB147T	TAB365T
Config	0-0	I-C
M_j	0.800	0.797
T_{Tj}/T_A	0.97	1.00
T_{Tj}, K	285.5	282.2
U_j, mps	255.2	252.9
Re_{De}	1.087	1.105
Re_h	0.482	0.490
Re_w	1.925	1.956
p_A, kPa	98.375	98.950
T_A, K	294.6	281.8
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	-0.44
$\Delta Y, mm$	-8.0	0.0

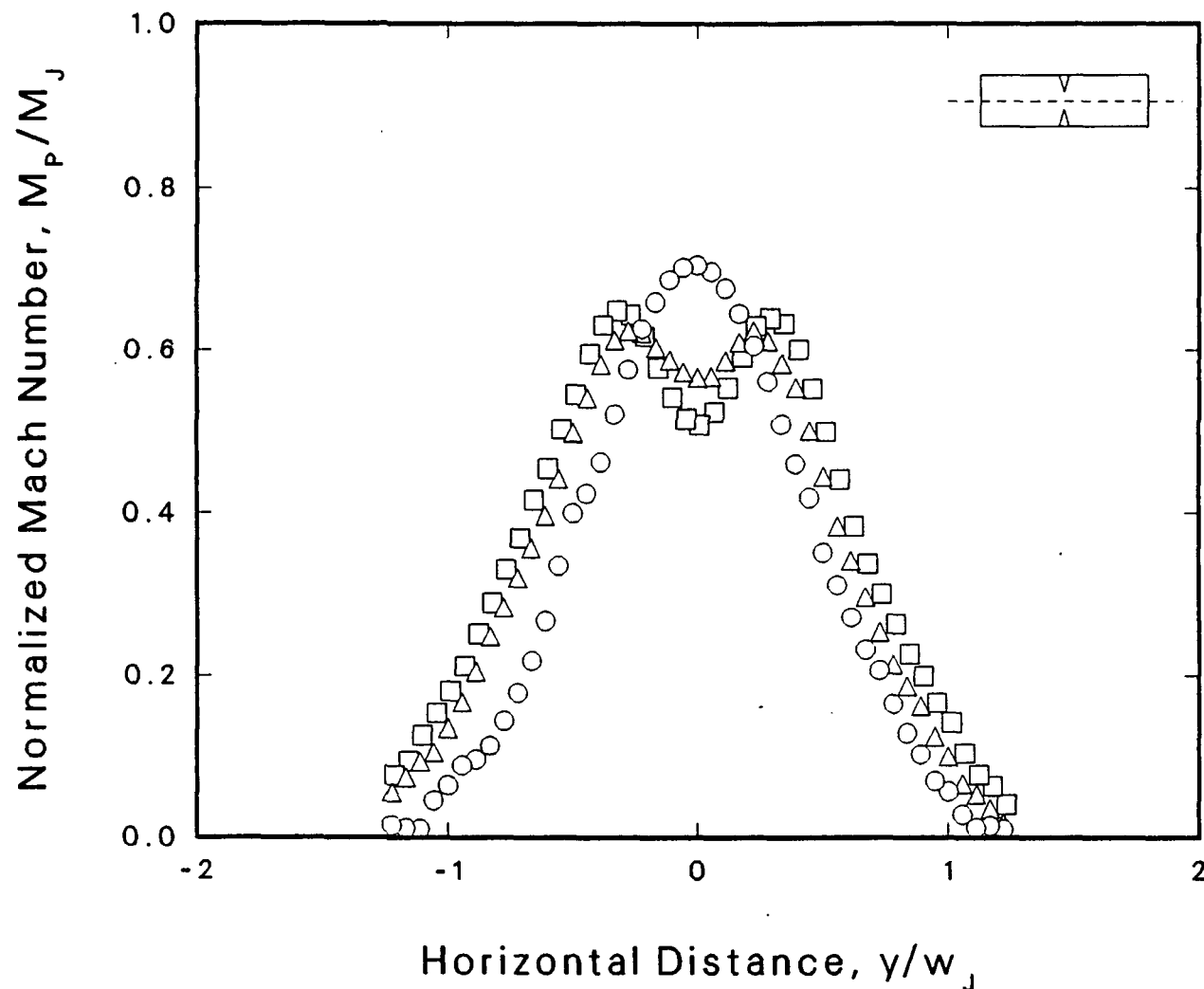
Figure B.60 Configuration I-C, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$



Sym	O	Δ
File	TAB146T	TAB364T
Config	0-0	I-C
M_j	0.800	0.797
T_{Tj}/T_A	0.97	1.01
T_{Tj}, K	285.8	281.8
U_j, mps	255.4	252.8
Re_{De}	1.086	1.108
Re_h	0.481	0.491
Re_w	1.922	1.960
p_A, kPa	98.375	98.916
T_A, K	294.9	280.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	1.0	-10.0

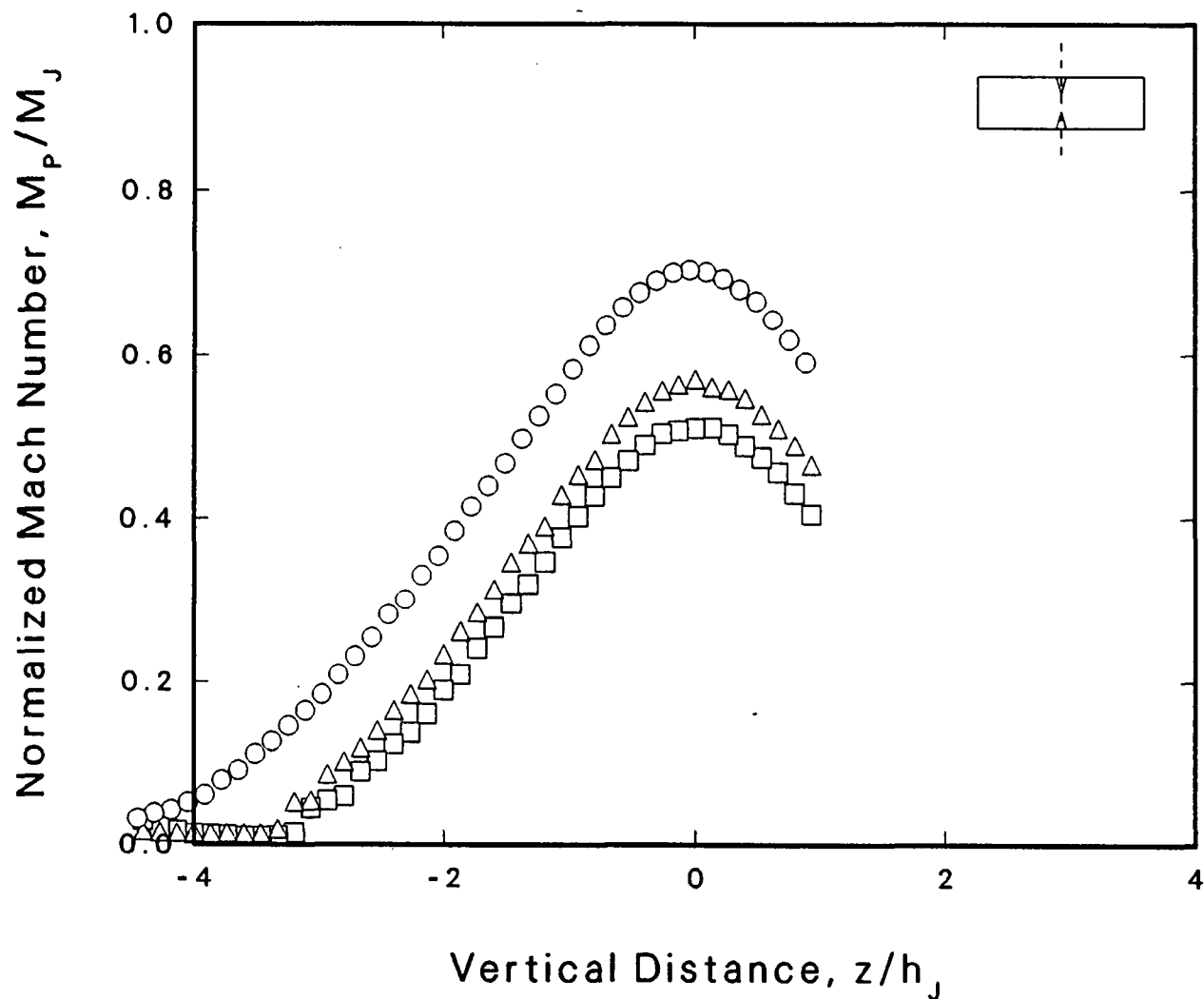
Figure B.61 Configuration I-C, Vertical Mach Number Profile,
 $X/De=9$, $M_j=0.8$, $T_j/T_0=1$

B-3.3 Mixing Modification for Unheated Supersonic Jets



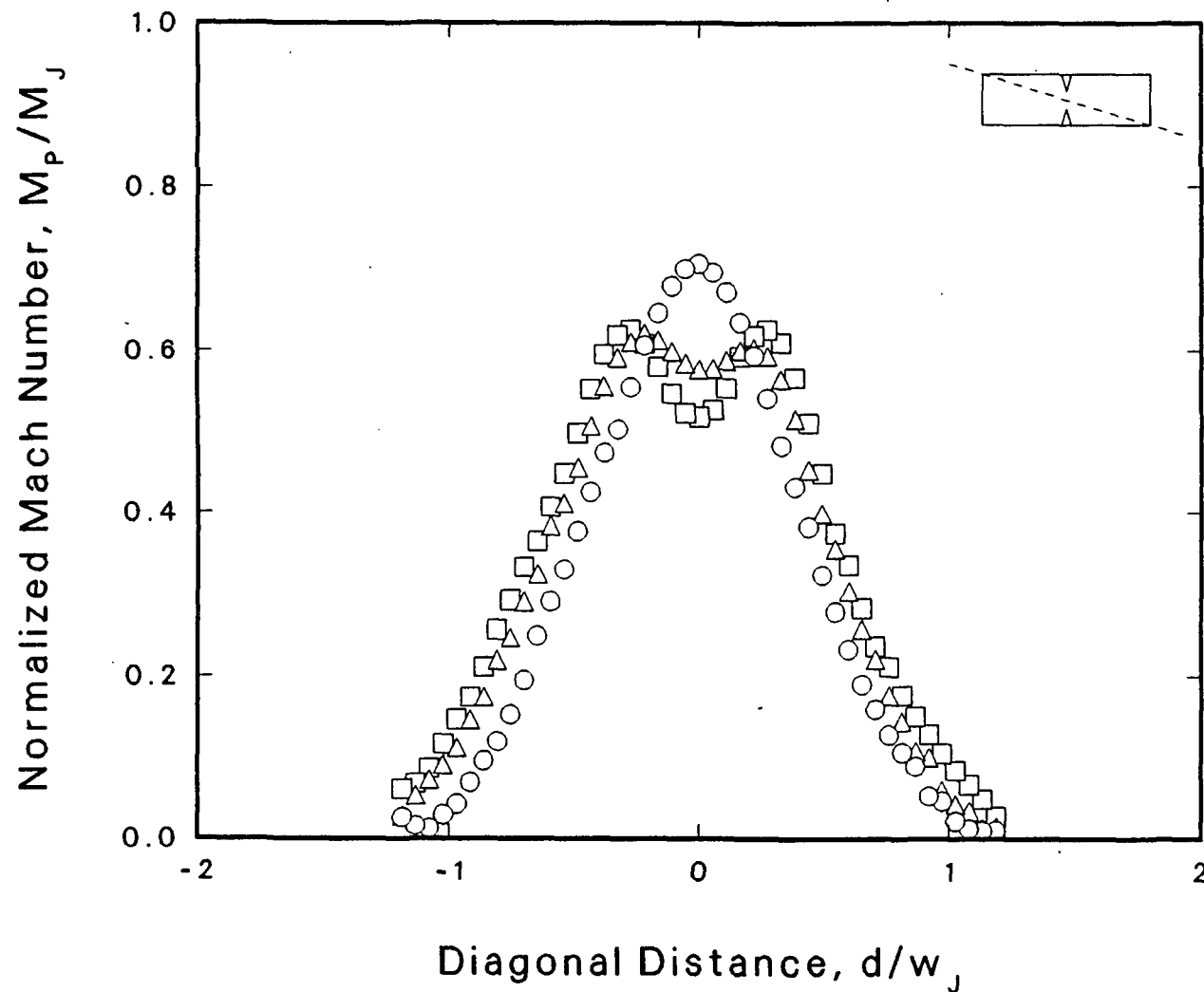
Sym	○	△	□
File	TAB185T	TAB187T	TAB196T
Config	0-0	I-A	I-B
M_j	1.148	1.151	1.148
T_{TJ}/T_A	1.01	0.99	1.00
T_{TJ}, K	283.3	283.9	283.7
U_j, mps	344.7	345.8	345.0
Re_{De}	1.831	1.842	1.827
Re_h	0.811	0.816	0.809
Re_w	3.241	3.261	3.233
p_A, kPa	98.273	98.781	98.205
T_A, K	280.4	286.1	284.7
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	-1.0

Figure B.62 Configuration I, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



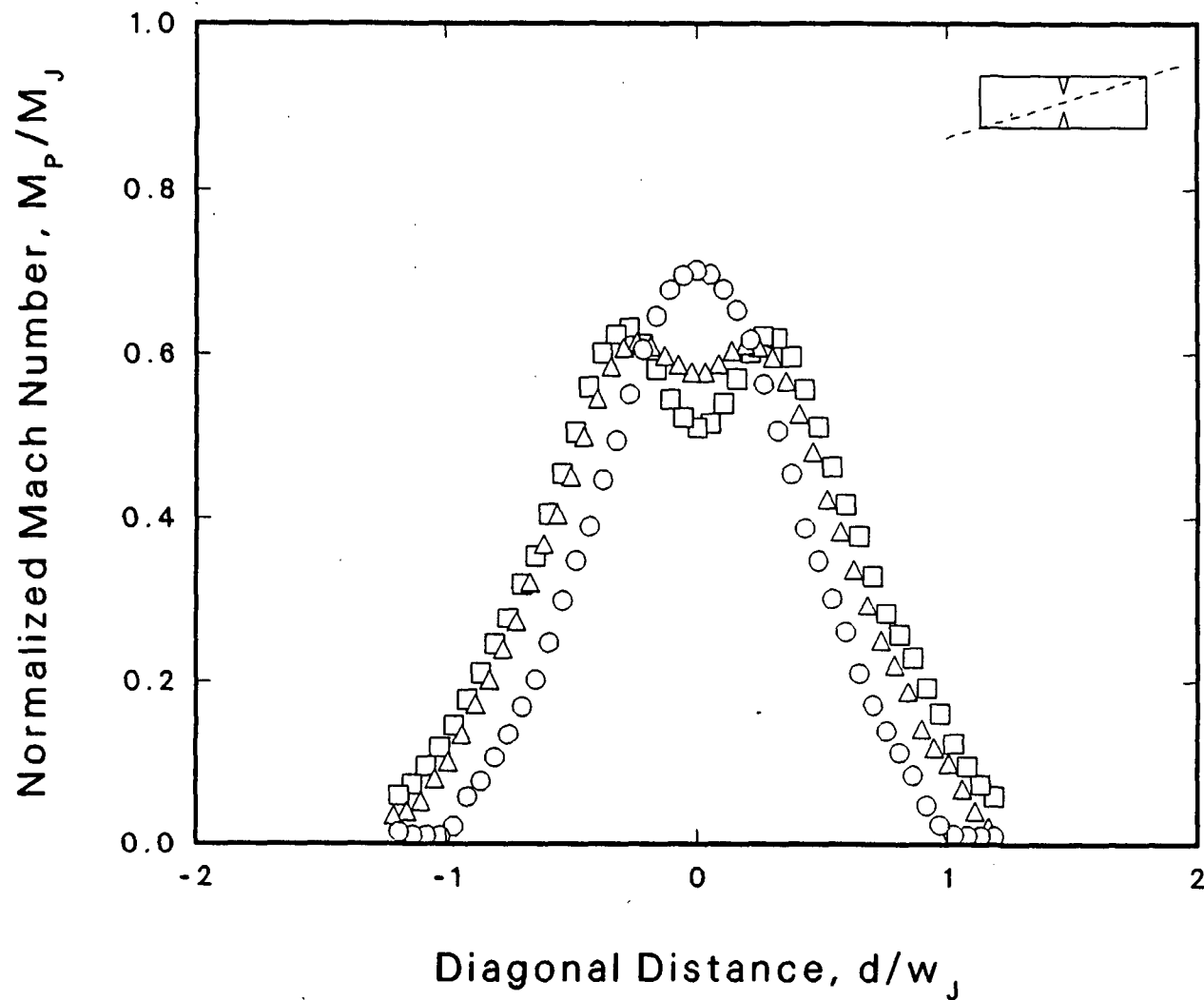
Sym	○	△	□
File	TAB203T	TAB204T	TAB195T
Config	0-0	I-A	I-B
M_j	1.151	1.149	1.149
T_{TJ}/T_A	0.99	1.00	1.00
T_{TJ}, K	283.1	283.1	283.5
U_j, mps	345.3	344.8	345.0
Re_{De}	1.842	1.836	1.831
Re_h	0.816	0.813	0.811
Re_w	3.260	3.249	3.241
p_A, kPa	98.375	98.341	98.273
T_A, K	284.7	284.4	283.6
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	0.0	-1.0	-1.0

Figure B.63 Configuration I, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$



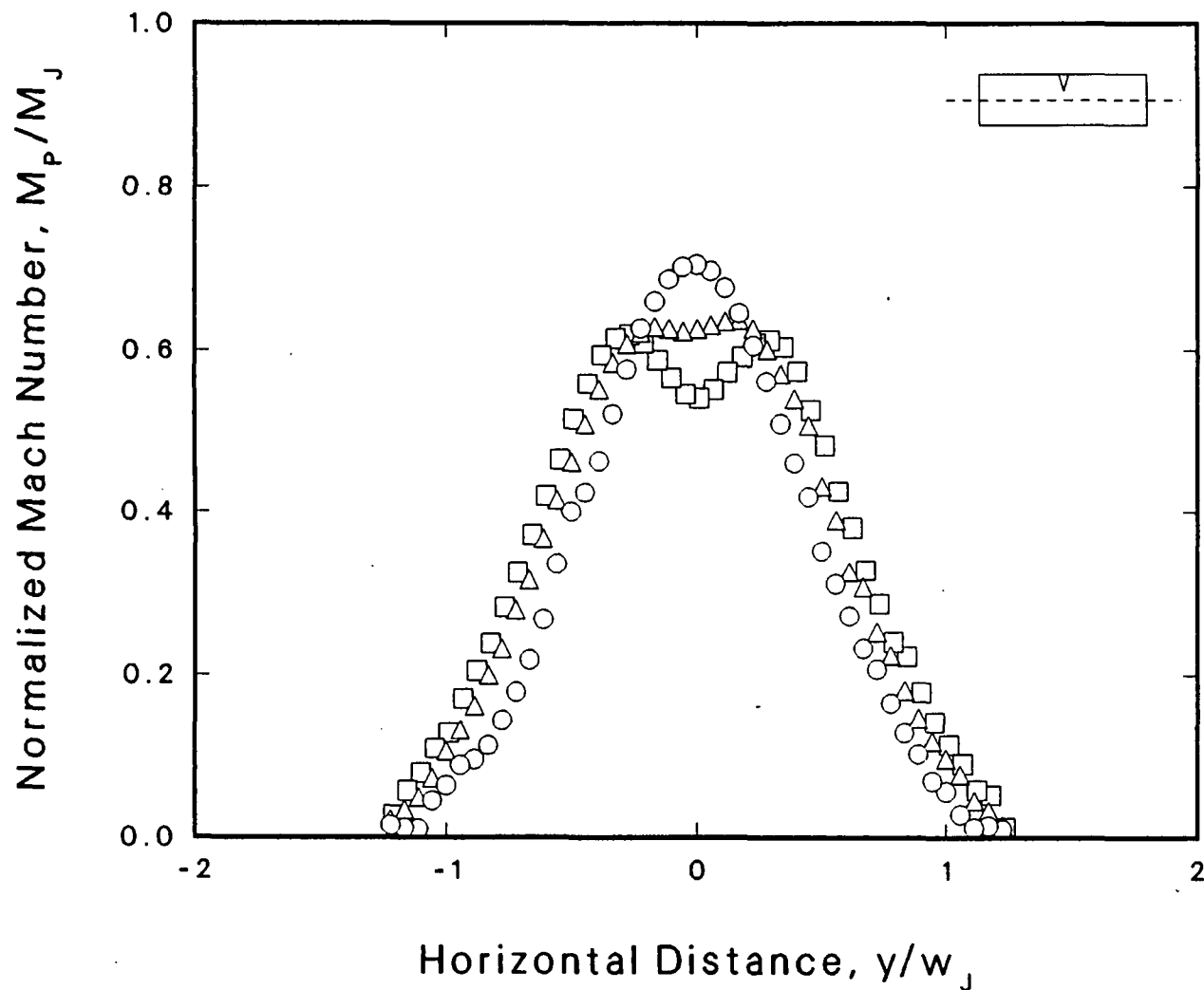
Sym	○	△	□
File	TAB209T	TAB210T	TAB213T
Config	0-0	I-A	I-B
M_j	1.144	1.150	1.146
T_{Tj}/T_A	0.99	0.98	0.99
T_{Tj} , K	281.8	282.4	282.0
U_j , mps	342.9	344.7	343.5
Re_{De}	1.849	1.855	1.848
Re_h	0.819	0.822	0.819
Re_w	3.374	3.385	3.372
p_A , kPa	99.086	98.849	98.815
T_A , K	283.4	287.1	285.1
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure B.64 Configuration I, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=-14^\circ$



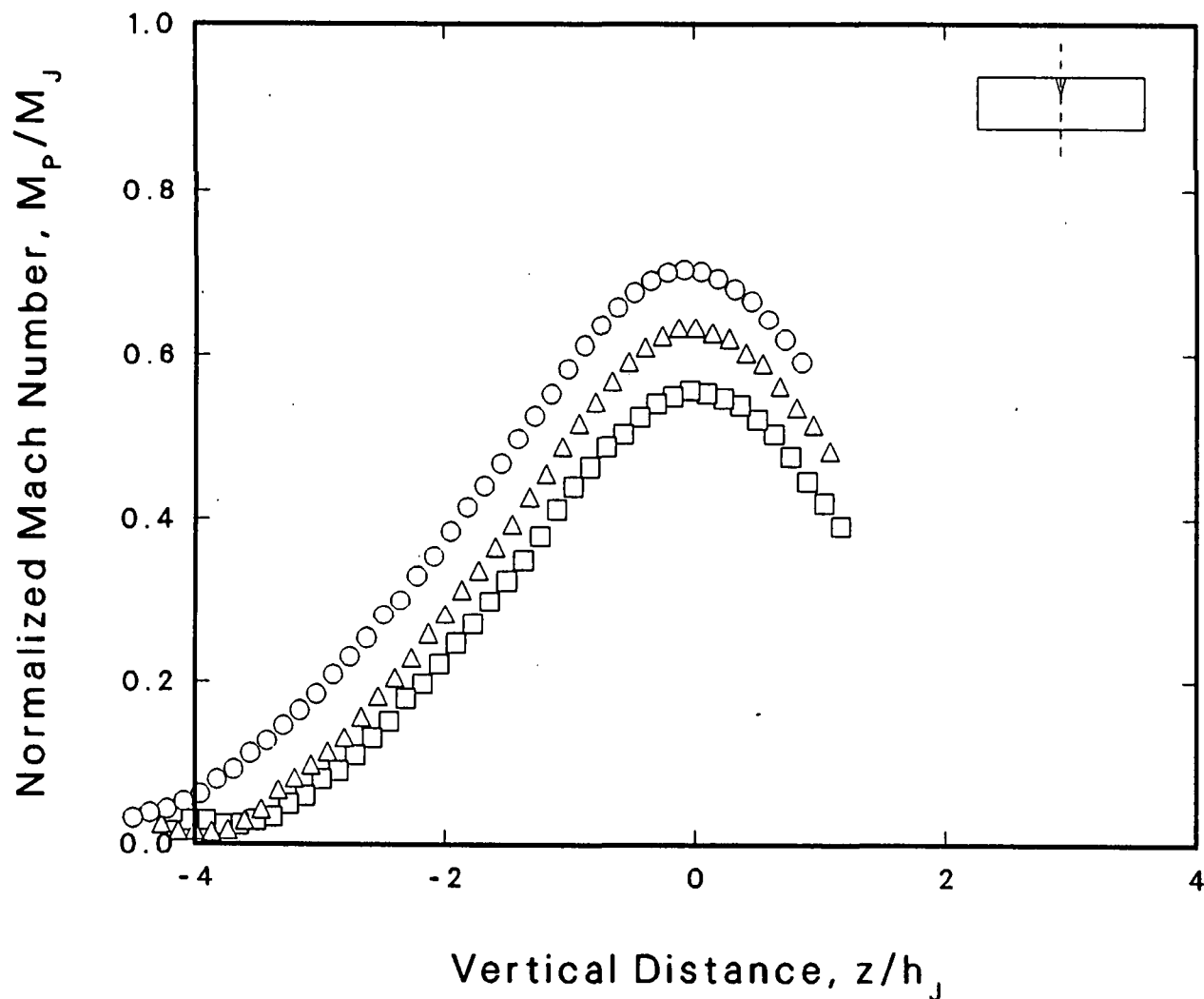
Sym	○	△	□
File	TAB221T	TAB223T	TAB226T
Config	0-0	I-A	I-B
M_j	1.147	1.148	1.150
T_{Tj}/T_A	0.98	0.98	1.01
T_{Tj} , K	282.3	283.1	283.9
U_j , mps	344.0	344.7	346.5
Re_{D_0}	1.844	1.836	1.833
Re_h	0.817	0.813	0.812
Re_w	3.364	3.351	3.345
p_A , kPa	98.578	98.408	98.442
T_A , K	289.5	290.2	281.7
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	2.0	0.0

Figure B.65 Configuration I, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$



Sym	○	△	□
File	TAB185T	TAB189T	TAB198T
Config	0-0	III-A	III-B
M_j	1.148	1.147	1.147
T_{TJ}/T_A	1.01	0.99	1.02
T_{TJ} , K	283.3	284.0	282.3
U_j , mps	344.7	344.8	343.8
Re_{De}	1.831	1.827	1.843
Re_h	0.811	0.809	0.816
Re_w	3.241	3.234	3.261
p_A , kPa	98.273	98.612	98.612
T_A , K	280.4	287.5	277.2
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	-1.0

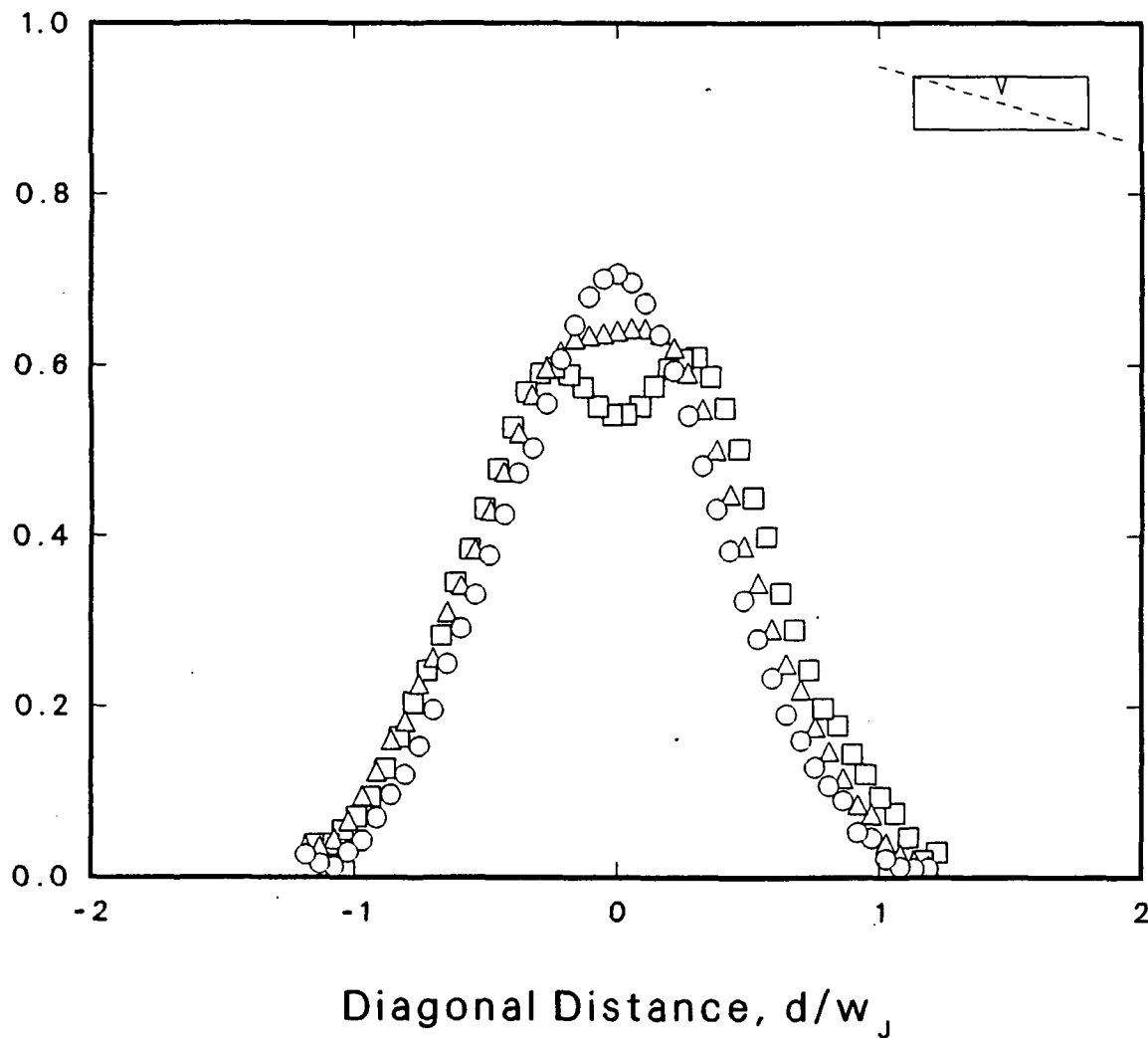
Figure B.66 Configuration III, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$



Sym	○	△	□
File	TAB203T	TAB205T	TAB197T
Config	0-0	III-A	III-B
M_j	1.151	1.147	1.148
T_{Tj}/T_A	0.99	1.00	1.03
T_{Tj} , K	283.1	283.1	282.0
U_j , mps	345.3	344.2	344.0
Re_{D_e}	1.842	1.830	1.848
Re_h	0.816	0.811	0.819
Re_w	3.260	3.240	3.271
p_A , kPa	98.375	98.341	98.578
T_A , K	284.7	284.0	273.9
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	1.0	-4.0	-6.0

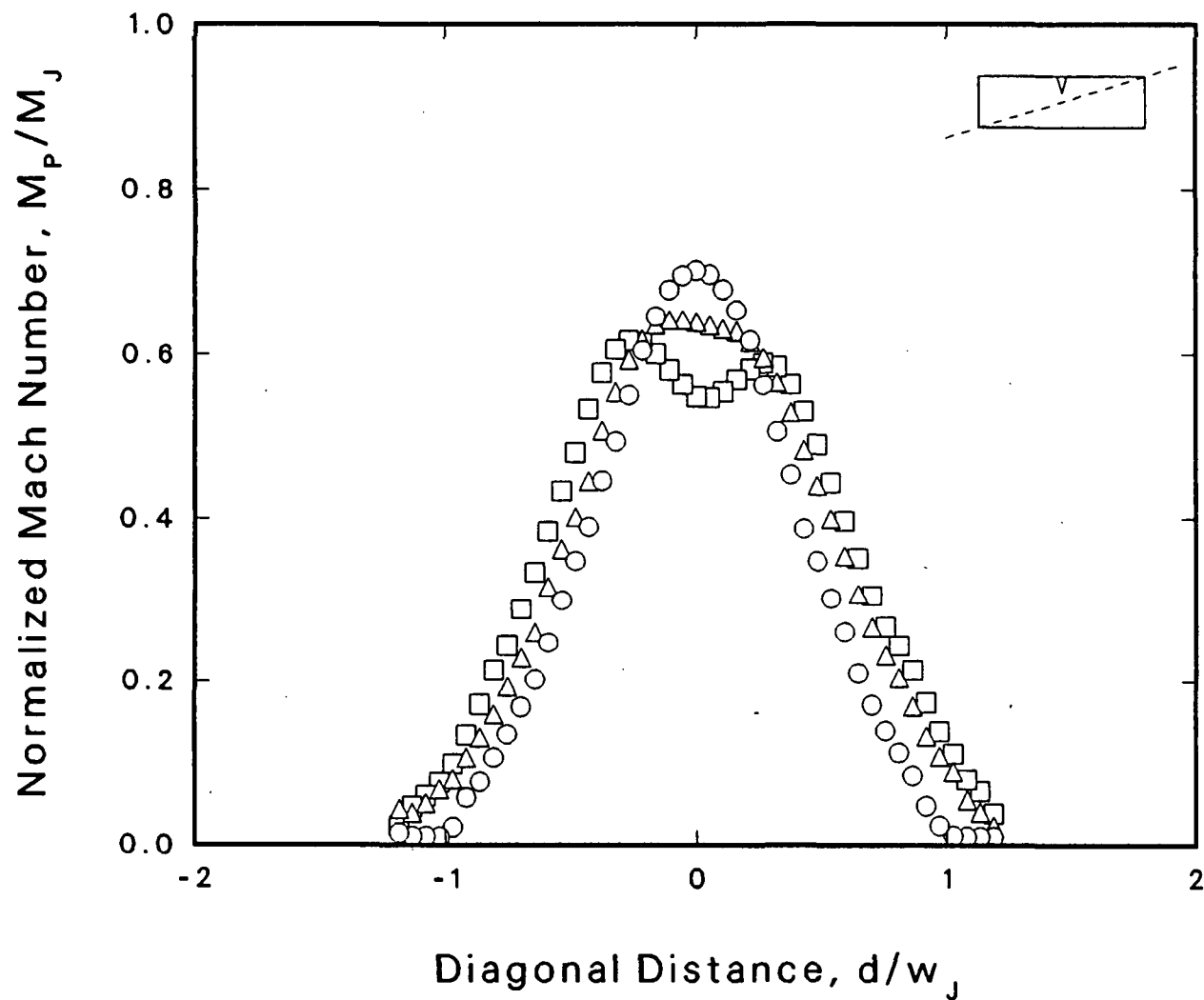
Figure B.67 Configuration III, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$

Normalized Mach Number, M_p/M_j



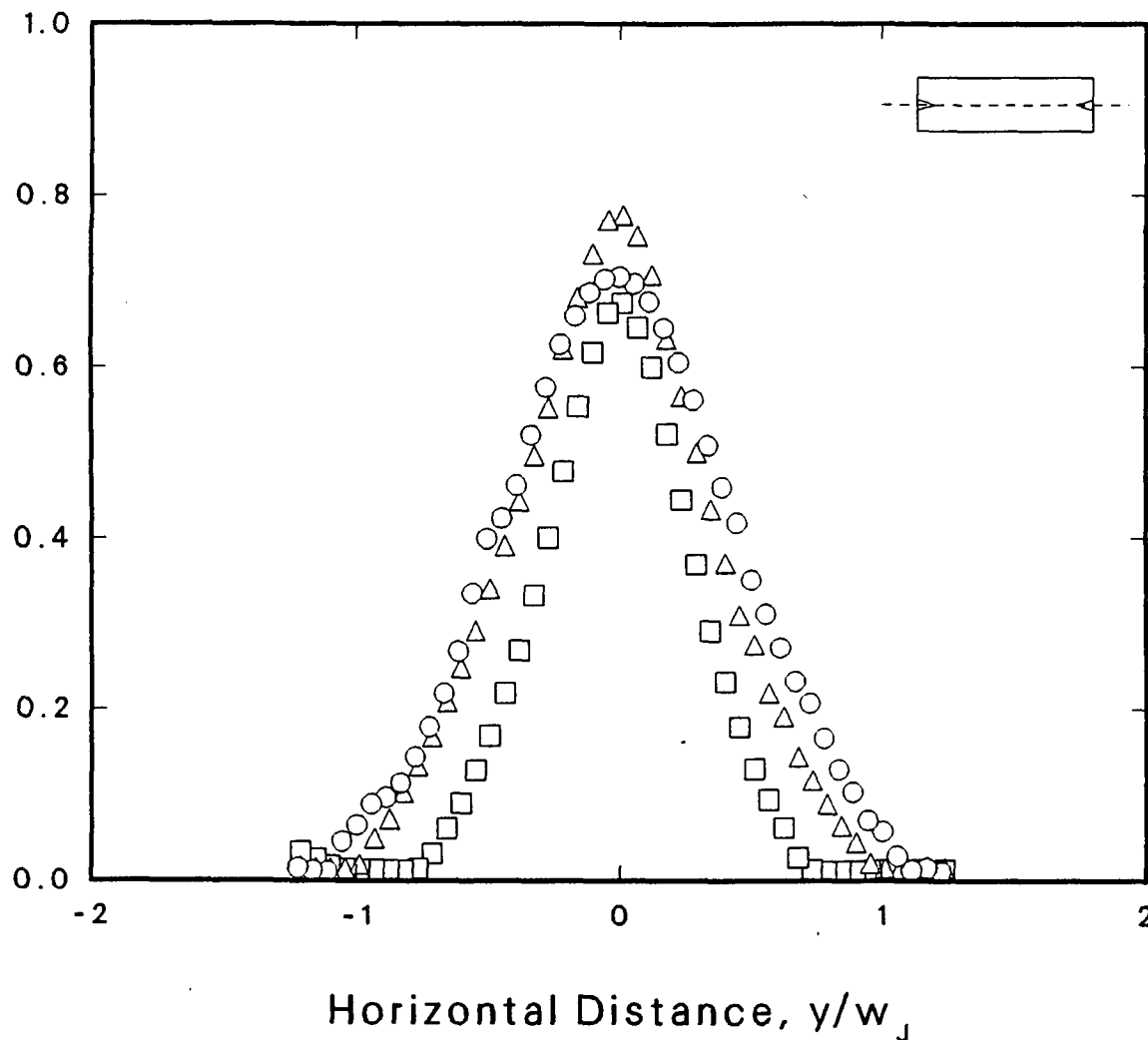
Sym	O	Δ	□
File	TAB209T	TAB215T	TAB214T
Config	0-0	III-A	III-B
M_j	1.144	1.150	1.149
T_{TJ}/T_A	0.99	0.97	0.97
T_{TJ}, K	281.8	283.0	282.7
U_j, mps	342.9	344.9	344.6
Re_{De}	1.849	1.840	1.845
Re_h	0.819	0.815	0.817
Re_w	3.374	3.358	3.366
p_A, kPa	99.086	98.408	98.612
T_A, K	283.4	291.2	290.4
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	-3.0

Figure B.68 Configuration III, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=-14^\circ$



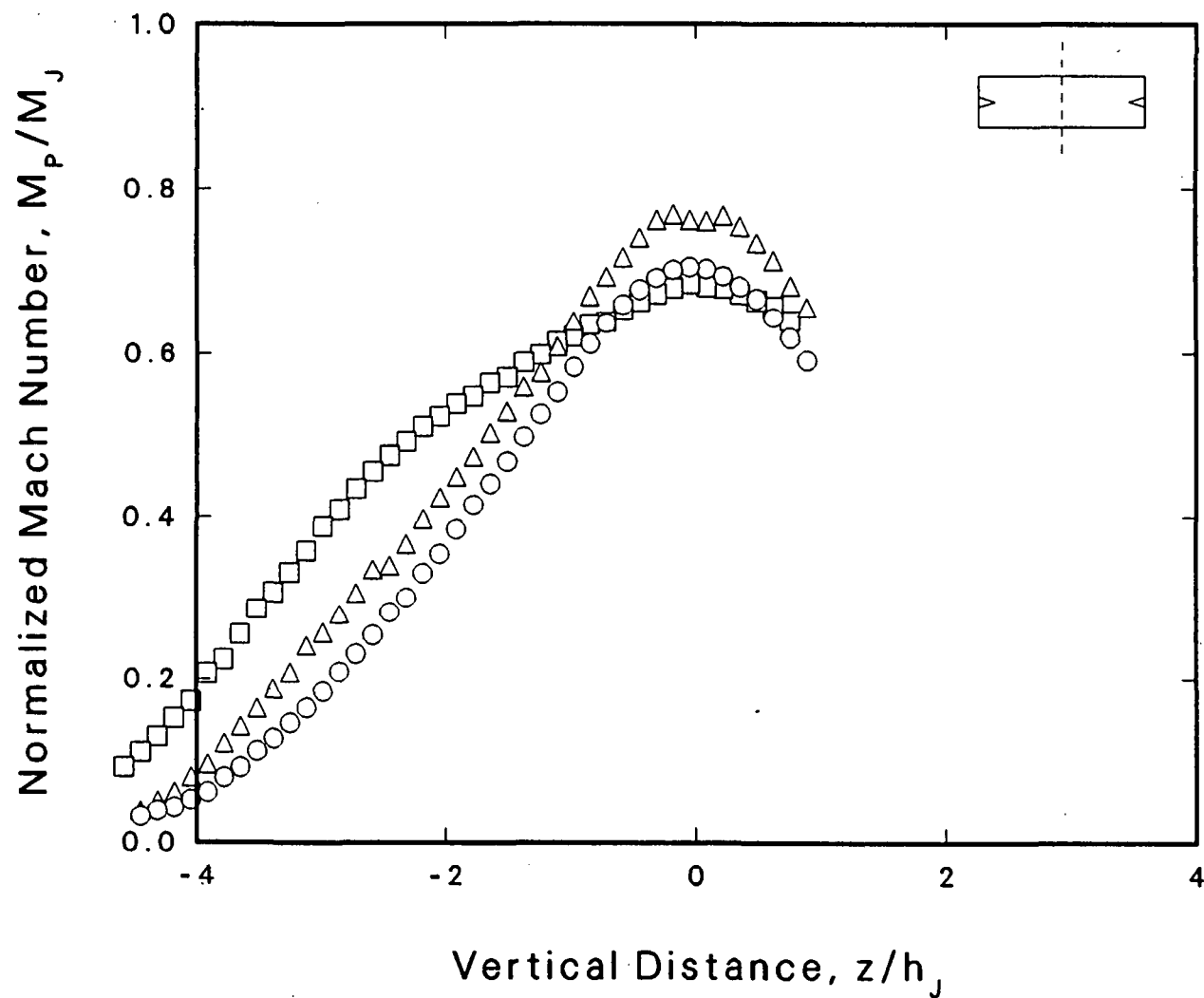
Sym	○	Δ	□
File	TAB221T	TAB224T	TAB227T
Config	0-0	III-A	III-B
M_j	1.147	1.149	1.148
T_{Tj}/T_A	0.98	1.01	1.00
T_{Tj} , K	282.3	281.6	284.0
U_j , mps	344.0	344.0	345.2
Re_{De}	1.844	1.854	1.829
Re_h	0.817	0.821	0.810
Re_w	3.364	3.382	3.338
p_A , kPa	98.578	98.510	98.476
T_A , K	289.5	278.6	284.6
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure B.69 Configuration III, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$



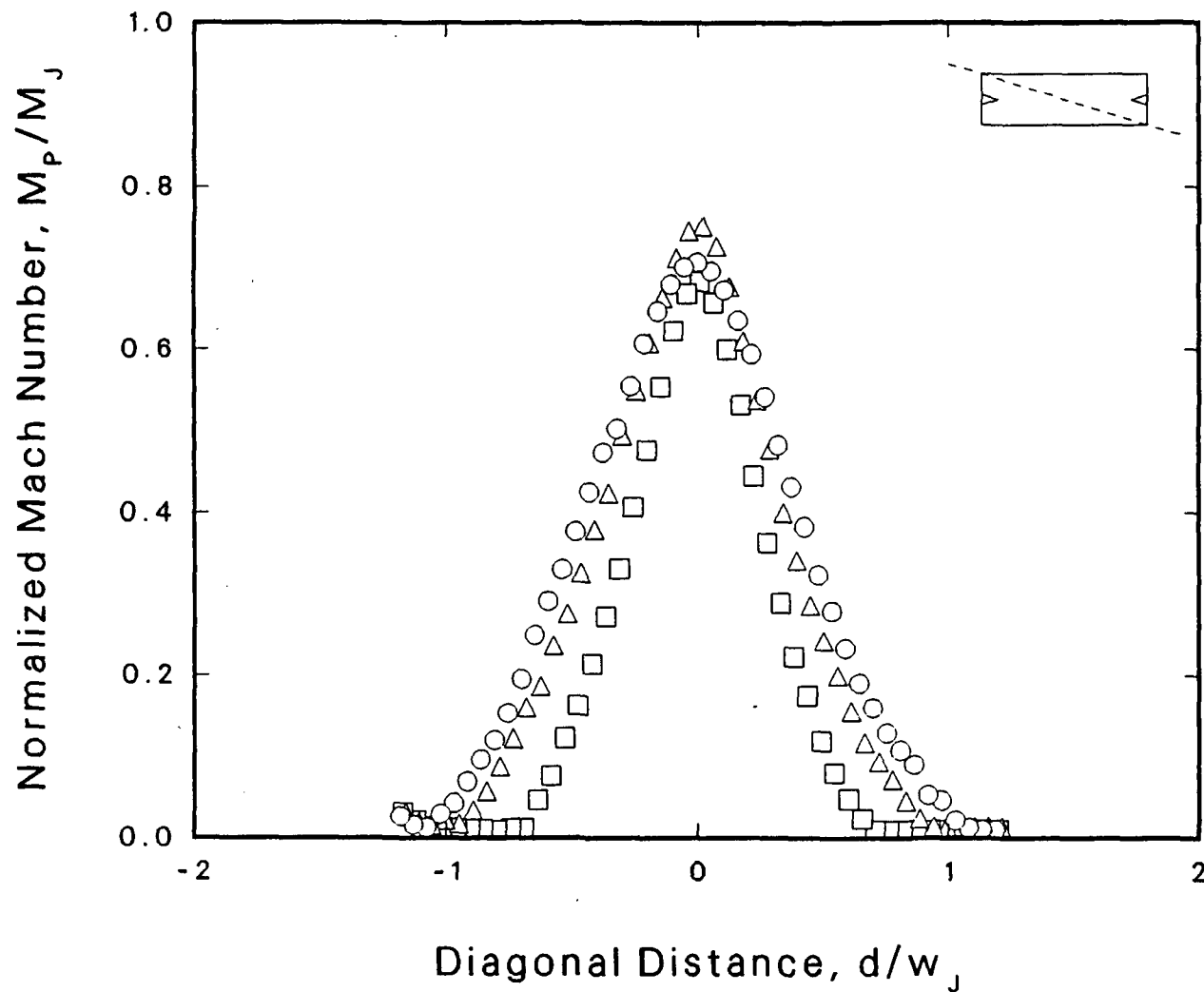
Sym	○	Δ	□
File	TAB185T	TAB200T	TAB191T
Config	0-0	II-B	II-A
M_j	1.148	1.145	1.149
T_{TJ}/T_A	1.01	1.00	1.01
T_{TJ}, K	283.3	282.7	283.0
U_j, mps	344.7	343.7	344.8
Re_{De}	1.831	1.837	1.837
Re_h	0.811	0.813	0.813
Re_w	3.241	3.251	3.251
p_A, kPa	98.273	98.679	98.341
T_A, K	280.4	281.9	279.1
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	-1.0	-1.0

Figure B.70 Configuration II, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$



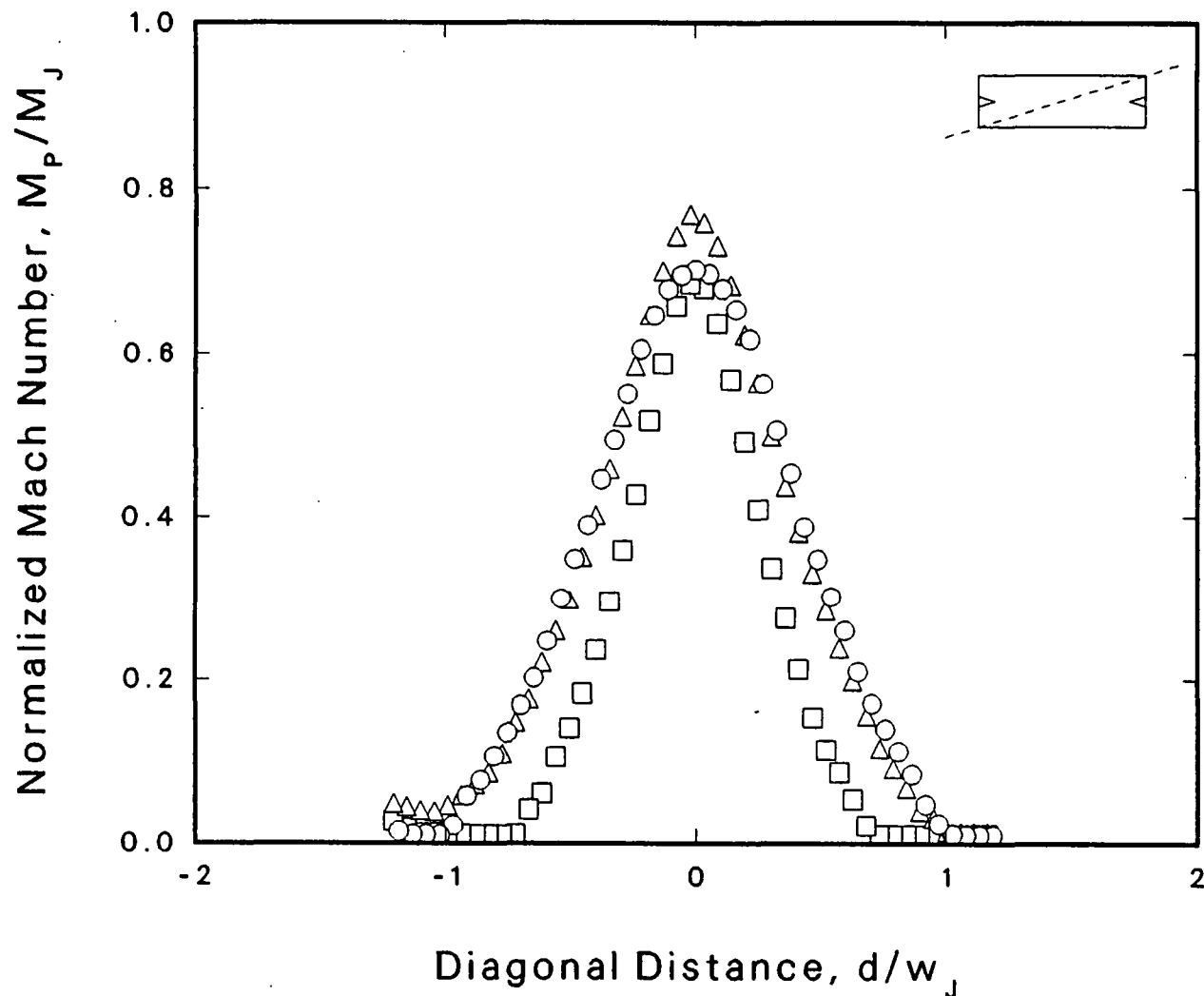
Sym	○	△	□
File	TAB203T	TAB199T	TAB206T
Config	0-0	II-B	II-A
M_j	1.151	1.146	1.148
T_{Tj}/T_A	0.99	1.01	1.00
T_{Tj} , K	283.1	282.5	282.9
U_j , mps	345.3	343.8	344.5
Re_{De}	1.842	1.841	1.837
Re_h	0.816	0.815	0.814
Re_w	3.260	3.258	3.252
p_A , kPa	98.375	98.646	98.408
T_A , K	284.7	280.0	283.6
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	0.0	0.0	3.0

Figure B.71 Configuration II, Vertical Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



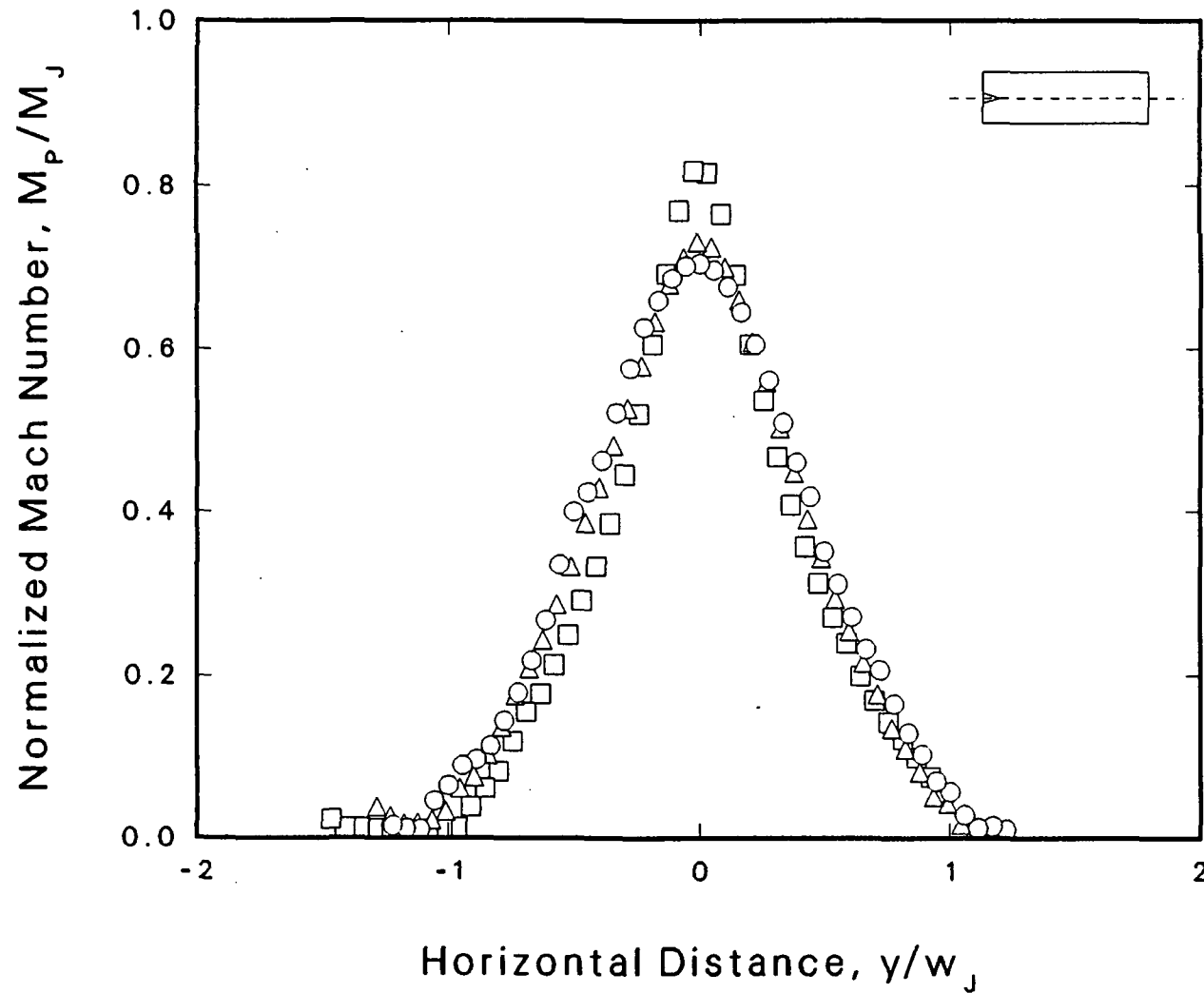
Sym	○	△	□
File	TAB209T	TAB219T	TAB220T
Config	0-0	II-B	II-A
M_j	1.144	1.149	1.149
T_{Tj}/T_A	0.99	0.97	0.97
T_{Tj}, K	281.8	282.7	282.9
U_j, mps	342.9	344.7	344.6
Re_{De}	1.849	1.836	1.831
Re_h	0.819	0.813	0.811
Re_w	3.374	3.350	3.341
p_A, kPa	99.086	98.070	98.036
T_A, K	283.4	290.6	291.6
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	-2.0	-1.0

Figure B.72 Configuration II, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=-14^\circ$



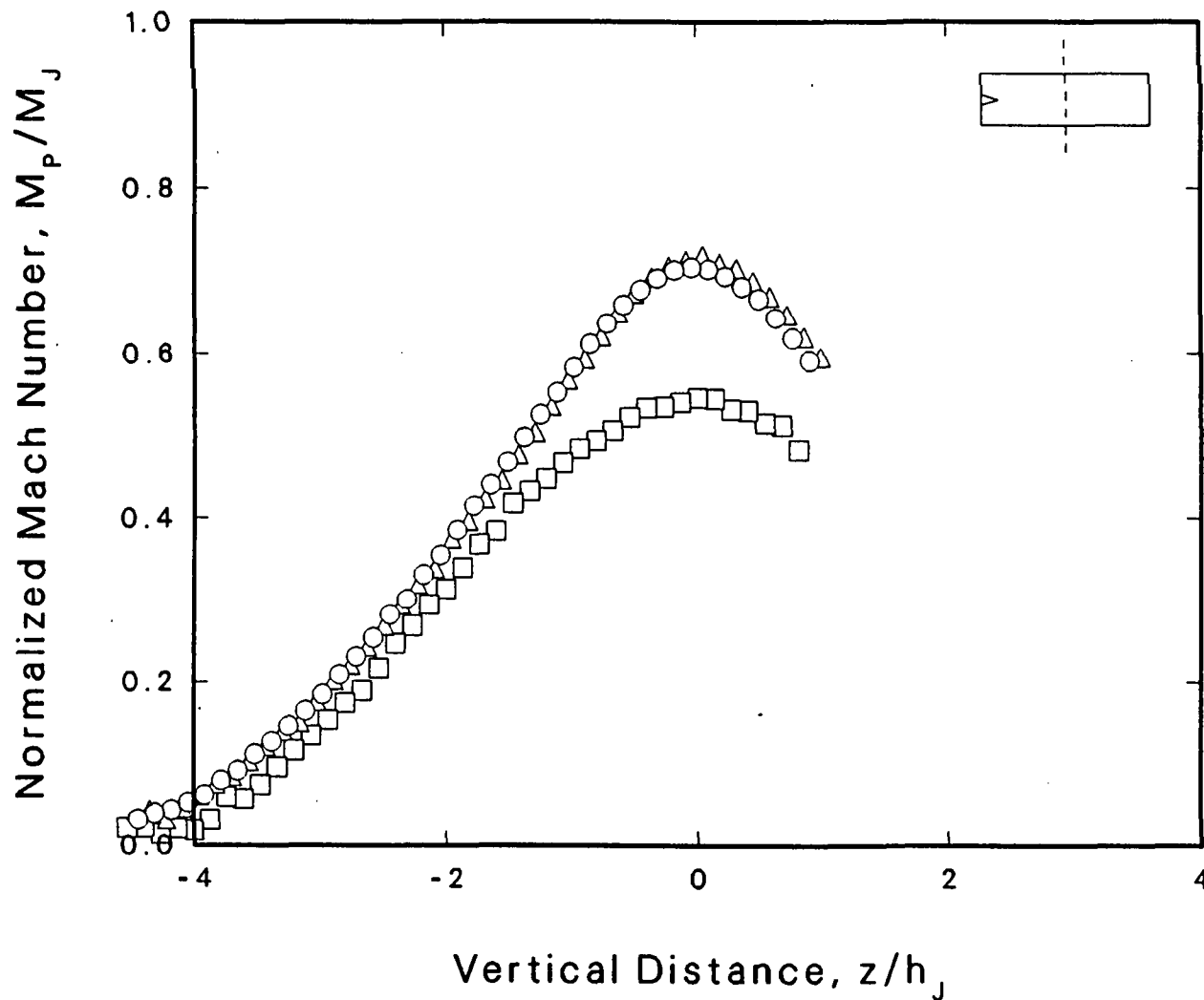
Sym	○	Δ	□
File	TAB221T	TAB231T	TAB228T
Config	0-0	II-B	II-A
M_j	1.147	1.147	1.148
T_{Tj}/T_A	0.98	1.03	0.99
T_{Tj} , K	282.3	282.5	284.1
U_j , mps	344.0	344.1	345.2
Re_{De}	1.844	1.841	1.828
Re_h	0.817	0.815	0.810
Re_w	3.364	3.359	3.336
p_A , kPa	98.578	98.544	98.476
T_A , K	289.5	274.7	286.2
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	2.0	2.0

Figure B.73 Configuration II, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$



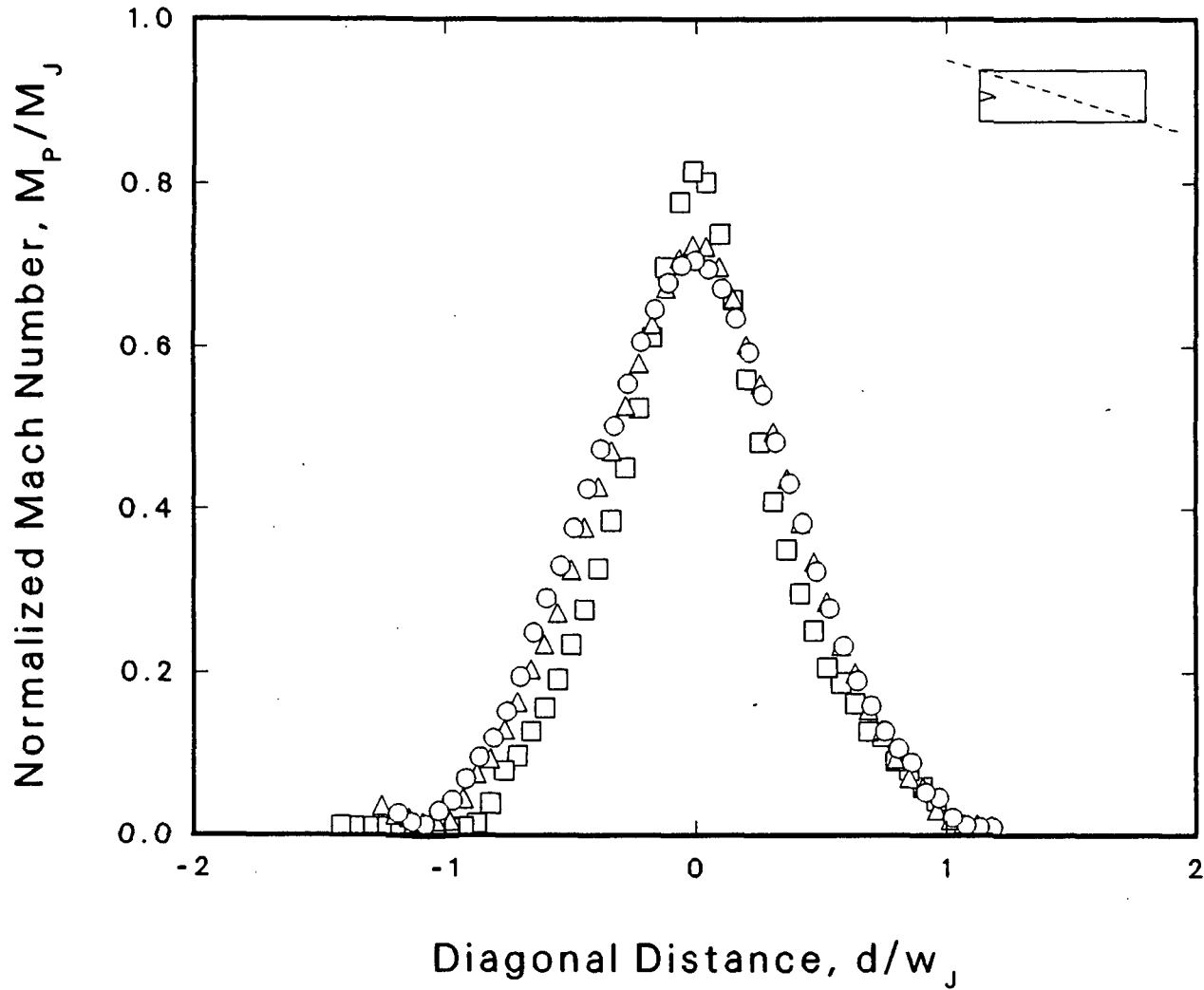
Sym	○	△	□
File	TAB185T	TAB202T	TAB193T
Config	0-0	IV-B	IV-A
M_j	1.148	1.148	1.147
T_{Tj}/T_A	1.01	0.99	1.01
T_{Tj} , K	283.3	283.2	283.1
U_j , mps	344.7	344.6	344.5
Re_{De}	1.831	1.834	1.833
Re_h	0.811	0.812	0.812
Re_w	3.241	3.246	3.244
p_A , kPa	98.273	98.442	98.375
T_A , K	280.4	285.6	281.3
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	6.0	22.0

Figure B.74 Configuration IV, Horizontal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$



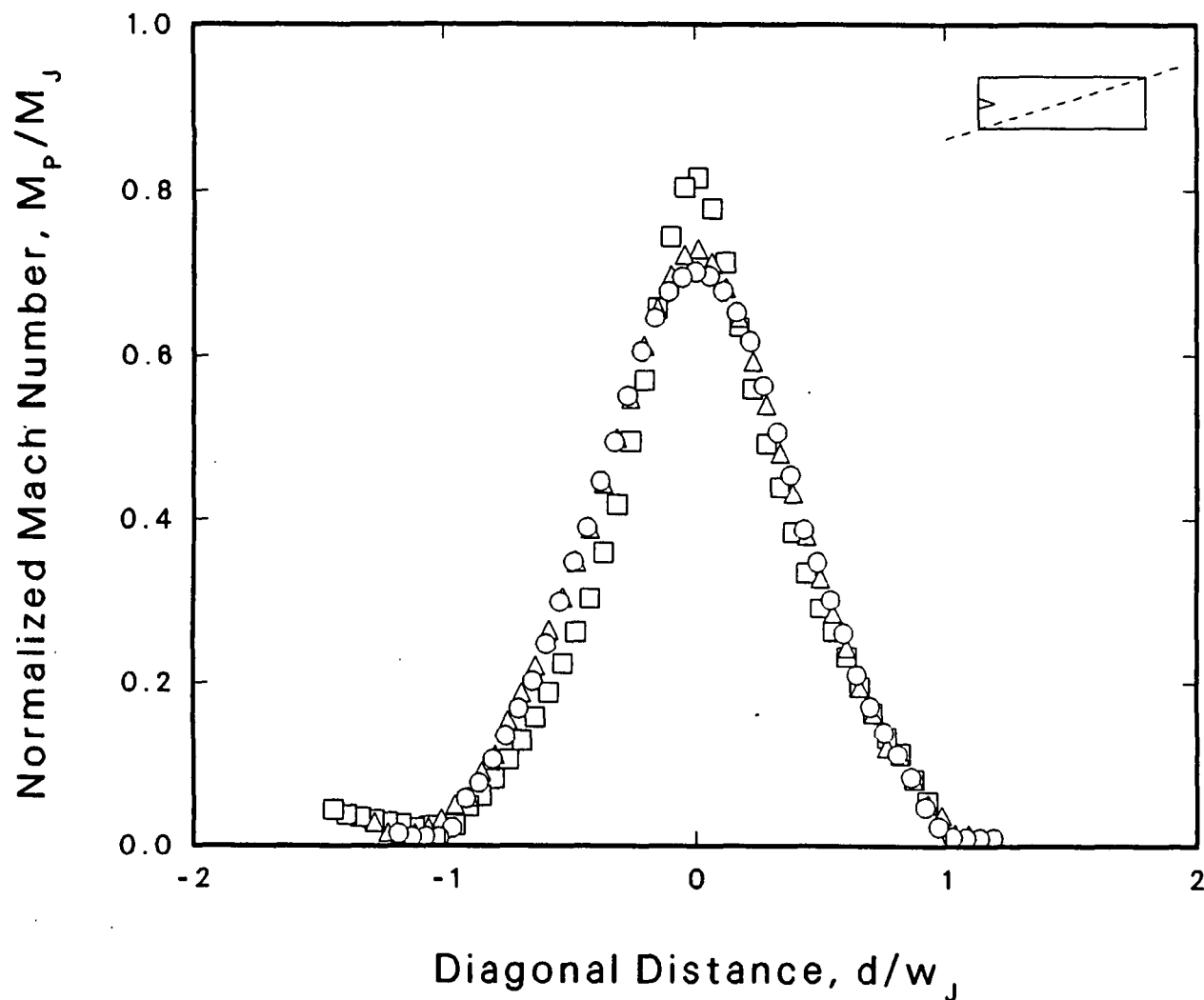
Sym	○	△	□
File	TAB203T	TAB201T	TAB207T
Config	0-0	IV-B	IV-A
M_j	1.151	1.147	1.148
T_{Tj}/T_A	0.99	1.00	1.00
T_{Tj}, K	283.1	282.9	282.8
U_j, mps	345.3	344.2	344.5
Re_{De}	1.842	1.839	1.839
Re_h	0.816	0.814	0.815
Re_w	3.260	3.255	3.256
p_A, kPa	98.375	98.646	98.476
T_A, K	284.7	283.4	282.4
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	0.0	-2.0	2.0

Figure B.75 Configuration IV, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$



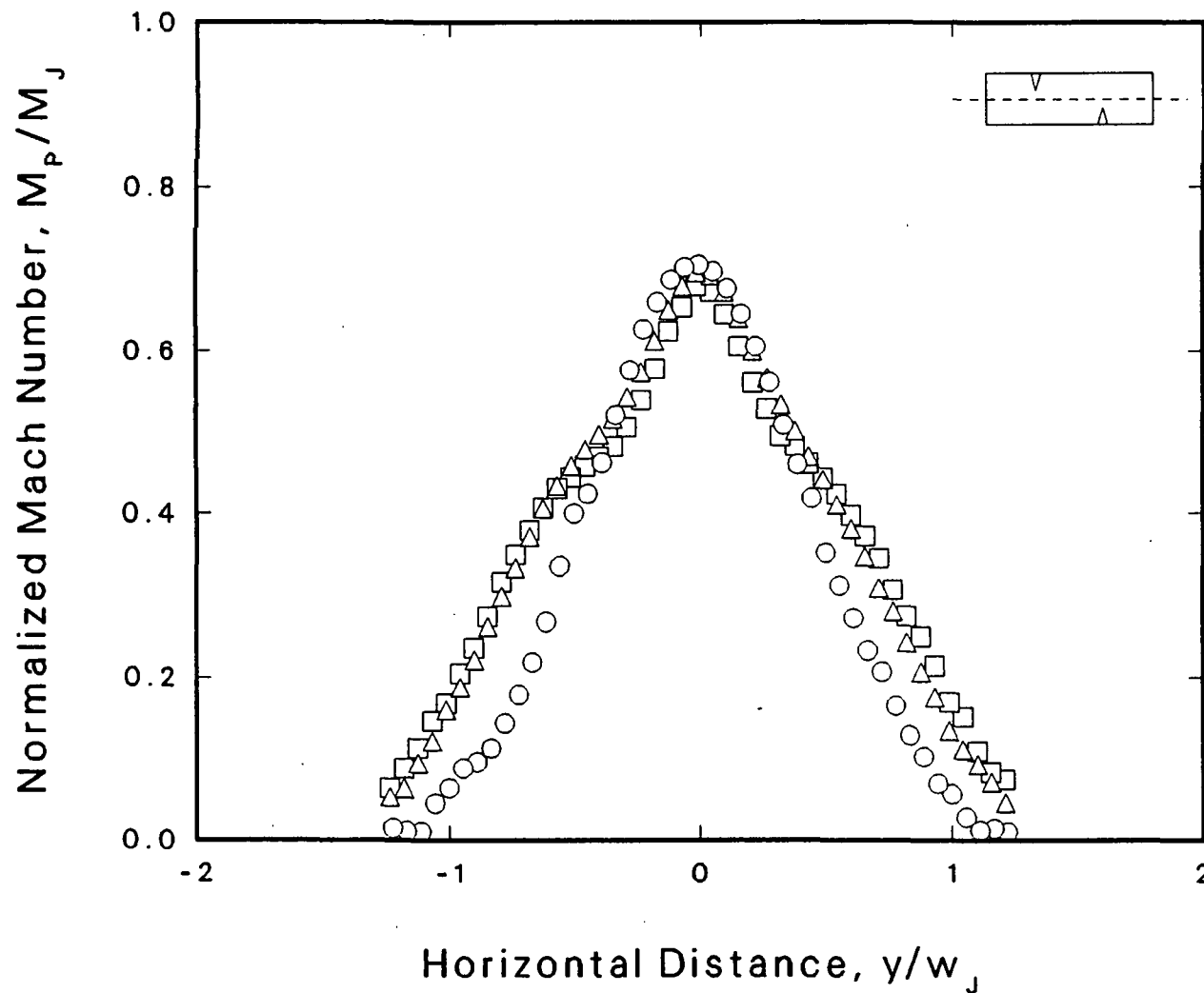
Sym	○	△	□
File	TAB209T	TAB218T	TAB217T
Config	0-0	IV-B	IV-A
M_j	1.144	1.150	1.145
T_{TJ}/T_A	0.99	0.97	0.99
T_{TJ}, K	281.8	282.9	281.8
U_j, mps	342.9	344.8	343.1
Re_{De}	1.849	1.836	1.838
Re_h	0.819	0.813	0.814
Re_w	3.374	3.350	3.353
p_A, kPa	99.086	98.138	98.307
T_A, K	283.4	290.3	283.5
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	6.0	21.0

Figure B.76 Configuration IV, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=-14^\circ$



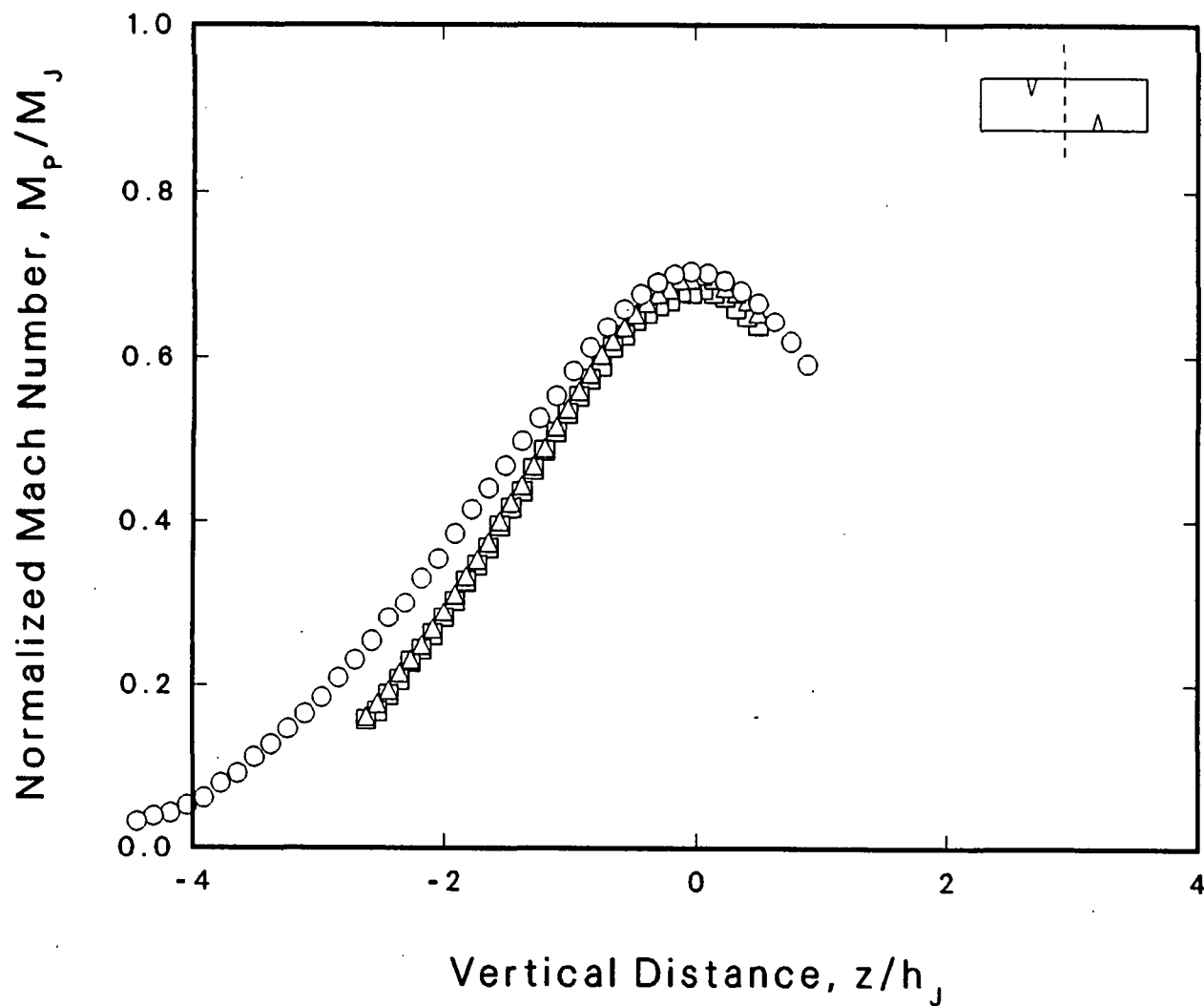
Sym	○	△	□
File	TAB221T	TAB232T	TAB230T
Config	0-0	IV-B	IV-A
M_j	1.147	1.148	1.147
T_{Tj}/T_A	0.98	1.02	0.98
T_{Tj} , K	282.3	280.3	282.0
U_j , mps	344.0	342.8	343.8
Re_{De}	1.844	1.862	1.844
Re_h	0.817	0.825	0.817
Re_w	3.364	3.398	3.365
p_A , kPa	98.578	98.578	98.476
T_A , K	289.5	274.7	287.6
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	9.0	24.0

Figure B.77 Configuration IV, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$



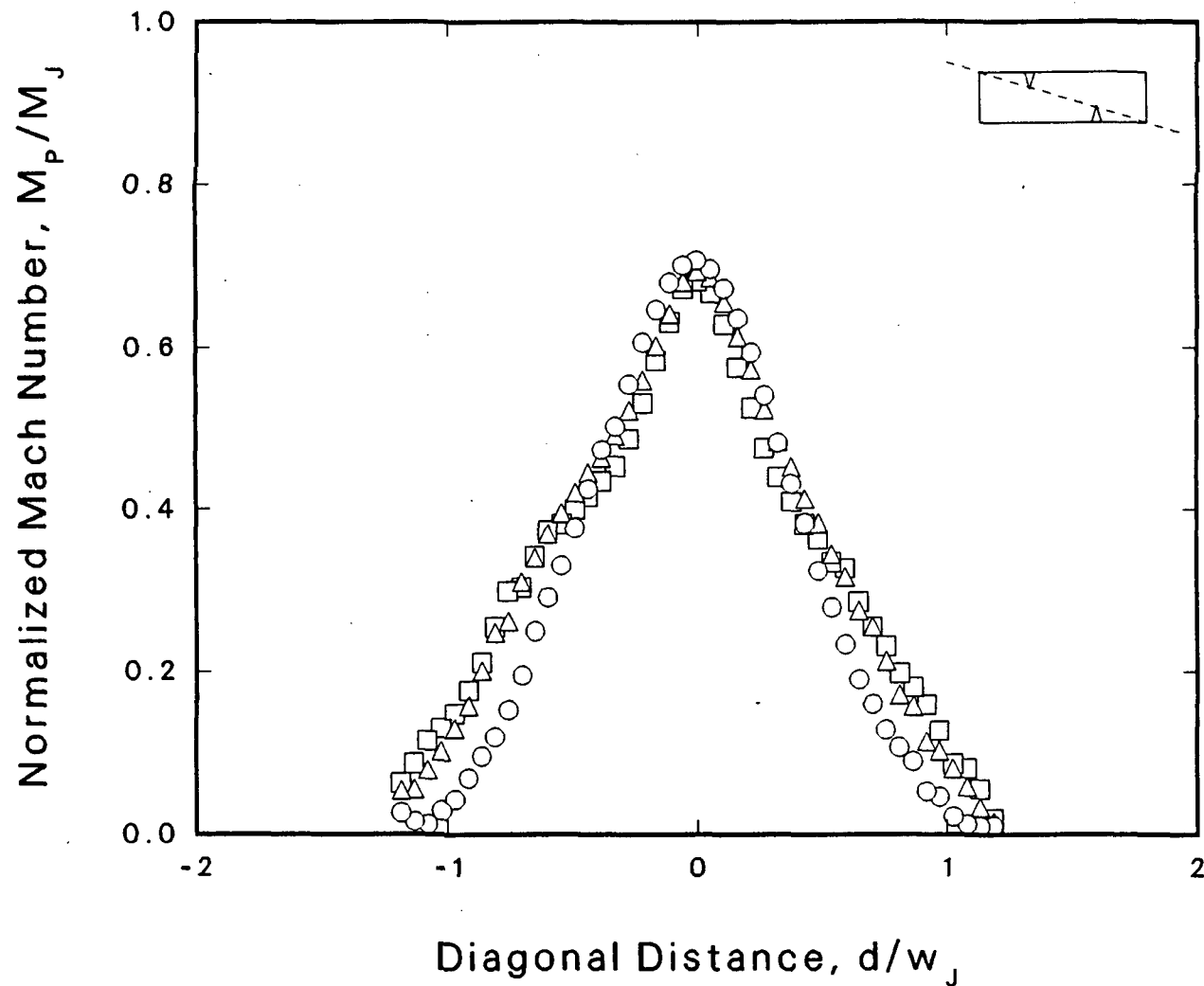
Sym	○	△	□
File	TAB185T	TAB243T	TAB251T
Config	0-0	VI-A	VI-B
M_j	1.148	1.149	1.147
T_{Tj}/T_A	1.01	0.99	1.01
T_{Tj} , K	283.3	280.7	279.5
U_j , mps	344.7	343.4	342.1
Re_{De}	1.831	1.843	1.861
Re_h	0.811	0.816	0.824
Re_w	3.241	3.263	3.294
p_A , kPa	98.273	97.596	98.307
T_A , K	280.4	282.5	276.0
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	1.0	1.0

Figure B.78 Configuration VI, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



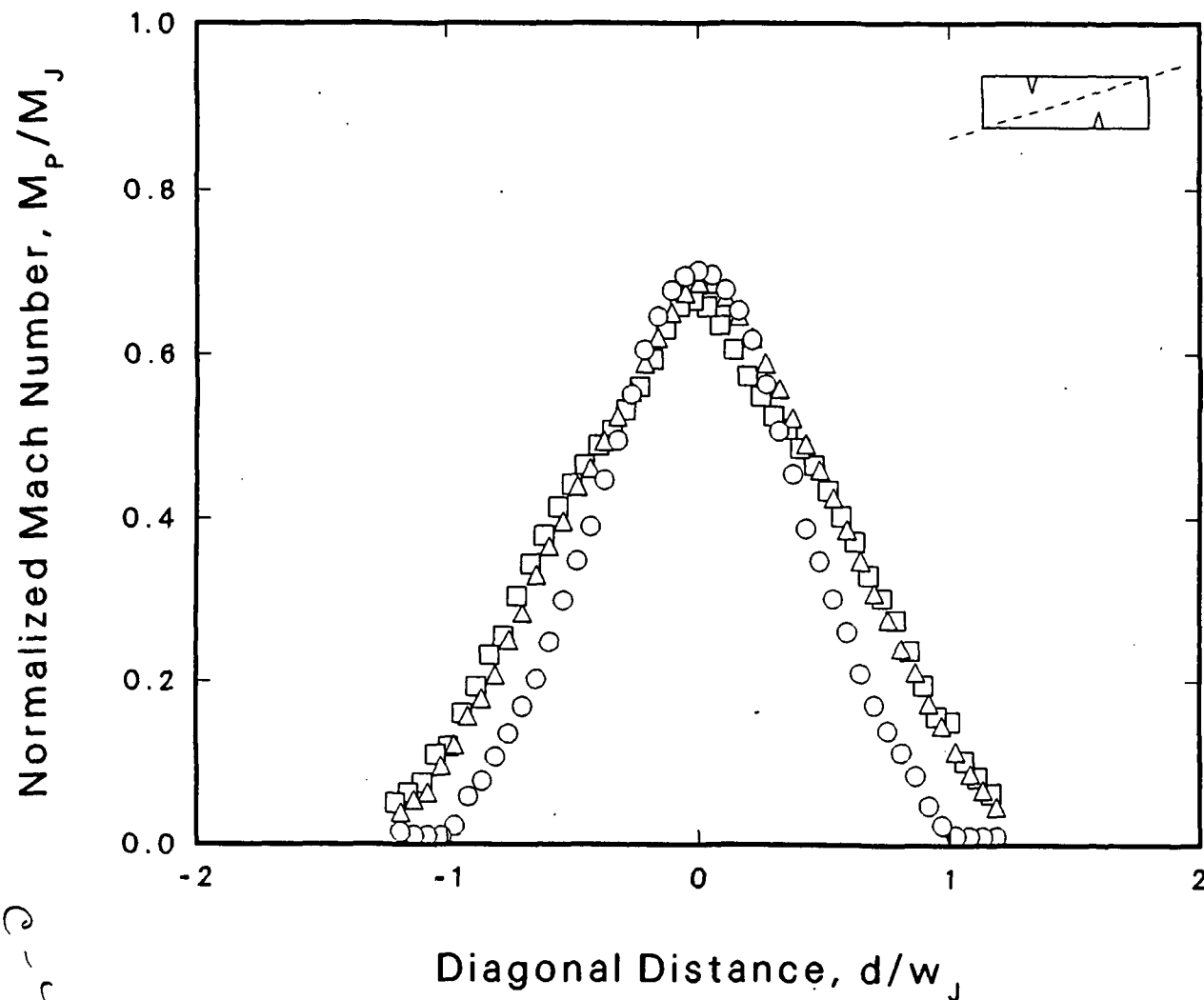
Sym	○	△	□
File	TAB203T	TAB244T	TAB250T
Config	0-0	VI-A	VI-B
M_j	1.151	1.149	1.147
T_{Tj}/T_A	0.99	0.99	1.02
T_{Tj} , K	283.1	280.5	279.6
U_j , mps	345.3	343.2	342.2
Re_{De}	1.842	1.843	1.860
Re_h	0.816	0.816	0.824
Re_w	3.260	3.263	3.292
p_A , kPa	98.375	97.562	98.273
T_A , K	284.7	283.1	275.1
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	0.0	-1.0	-1.0

Figure B.79 Configuration VI, Vertical Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$



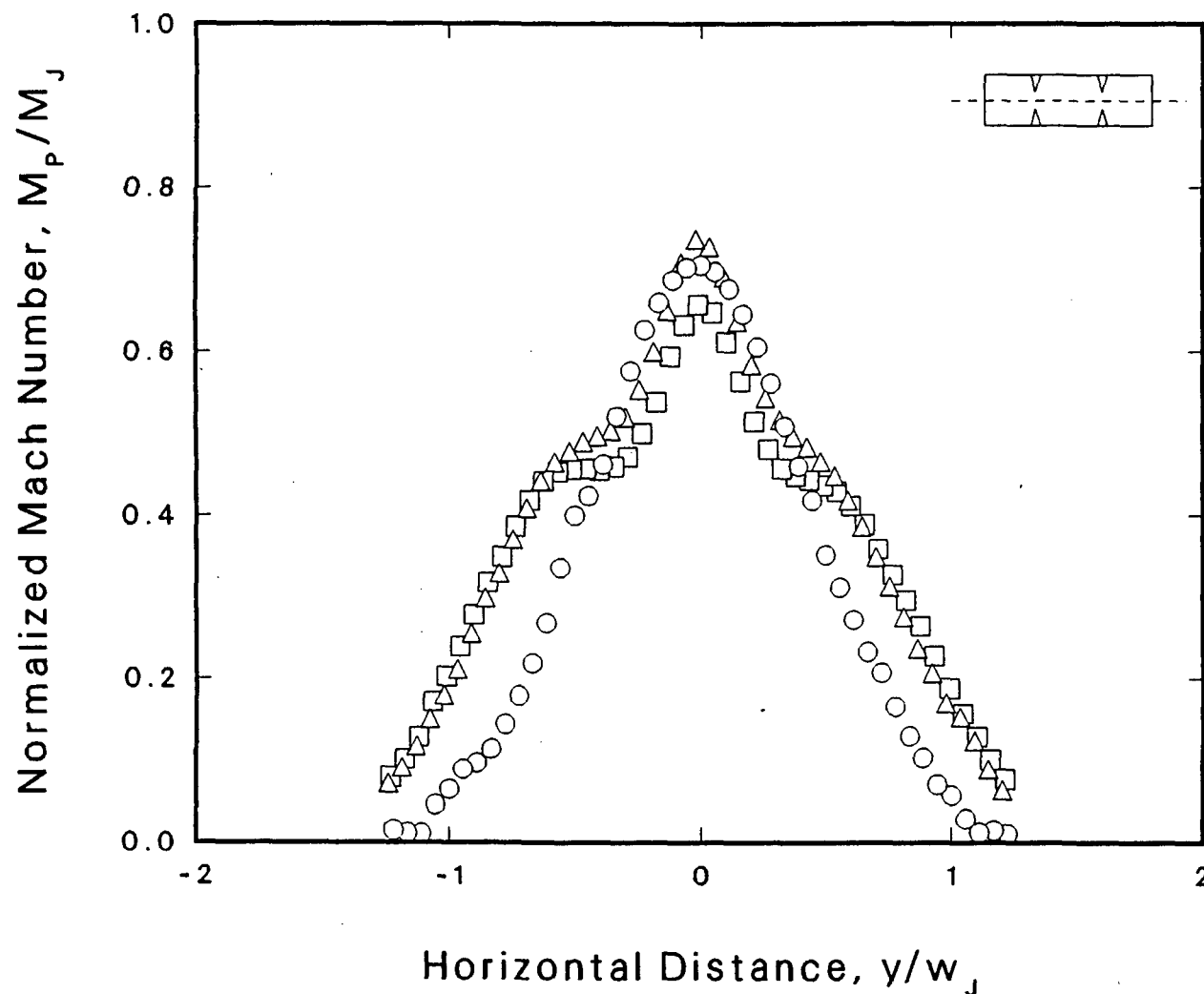
Sym	○	△	□
File	TAB209T	TAB258T	TAB263T
Config	0-0	VI-A	VI-B
M_j	1.144	1.147	1.147
T_{Tj}/T_A	0.99	0.99	1.01
T_{Tj}, K	281.8	281.4	279.5
U_j, mps	342.9	343.4	342.1
Re_{De}	1.849	1.850	1.867
Re_h	0.819	0.819	0.827
Re_w	3.374	3.376	3.407
p_A, kPa	99.086	98.476	98.544
T_A, K	283.4	283.9	275.8
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	0.0

Figure B.80 Configuration VI, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=-14^\circ$



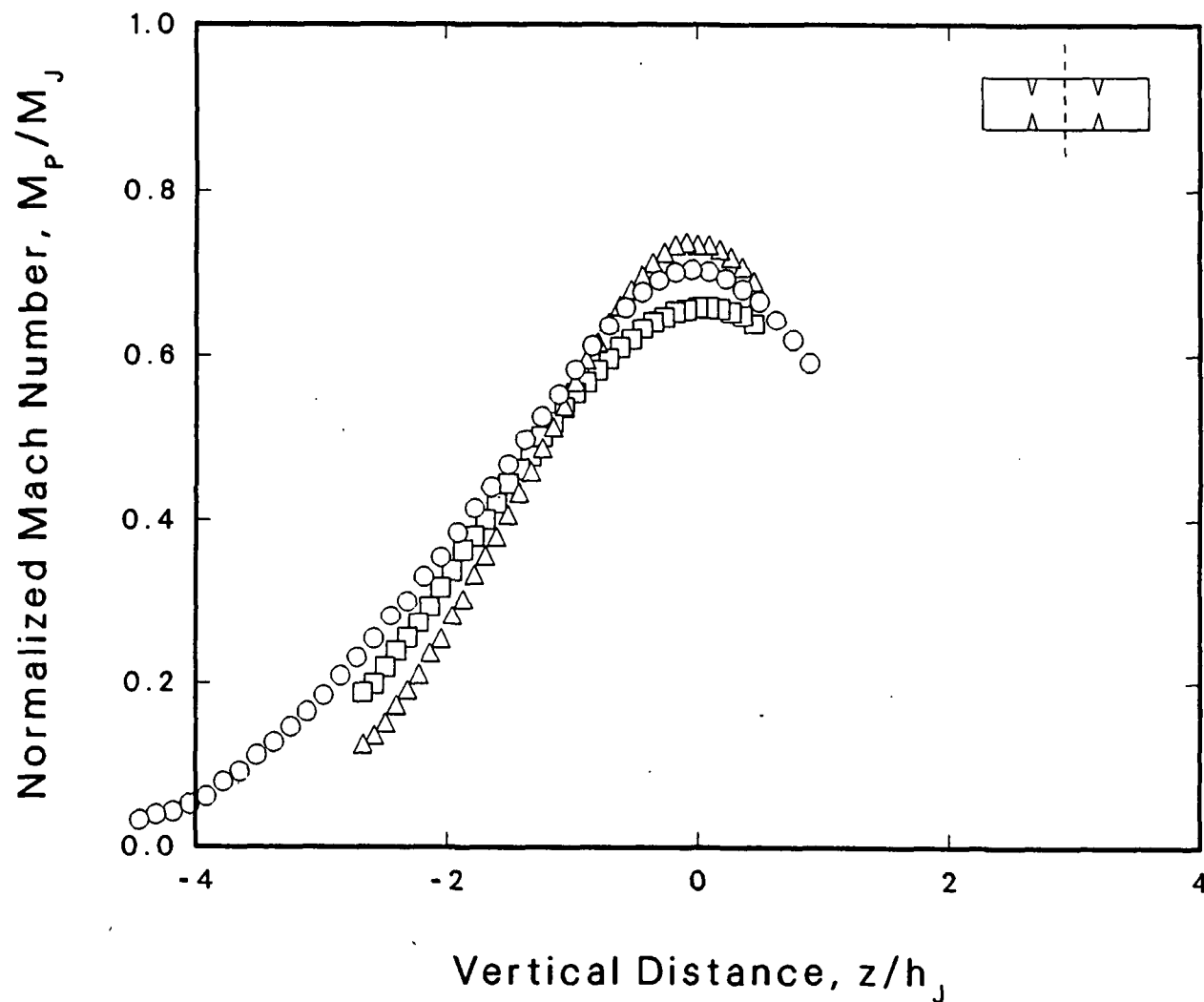
Sym	○	Δ	□
File	TAB221T	TAB234T	TAB236T
Config	0-0	VI-A	VI-B
M_j	1.147	1.148	1.150
T_{Tj}/T_A	0.98	1.00	1.00
T_{Tj} , K	282.3	280.6	280.3
U_j , mps	344.0	343.1	343.2
Re_{De}	1.844	1.857	1.859
Re_h	0.817	0.822	0.823
Re_w	3.364	3.388	3.392
p_A , kPa	98.578	98.375	98.171
T_A , K	289.5	280.7	279.9
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	2.0

Figure B.81 Configuration VI, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$



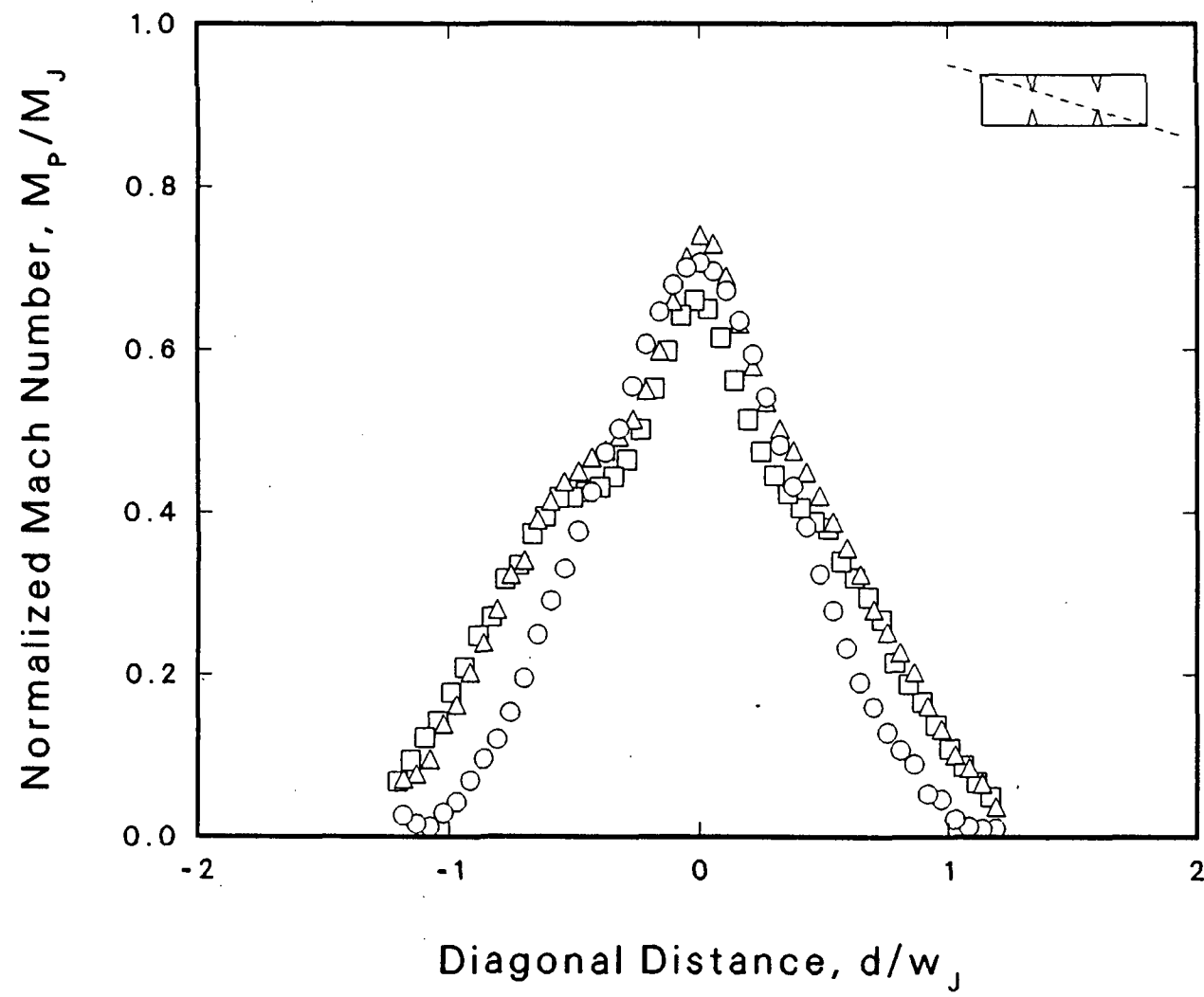
Sym	○	Δ	□
File	TAB185T	TAB238T	TAB247T
Config	0-0	VII-A	VII-B
M_j	1.148	1.148	1.148
T_{Tj}/T_A	1.01	0.99	0.98
T_{Tj}, K	283.3	281.1	281.1
U_j, mps	344.7	343.3	343.4
Re_{De}	1.831	1.849	1.829
Re_h	0.811	0.819	0.810
Re_w	3.241	3.273	3.237
p_A, kPa	98.273	98.239	97.122
T_A, K	280.4	285.3	286.9
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	2.0	1.0

Figure B.82 Configuration VII, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



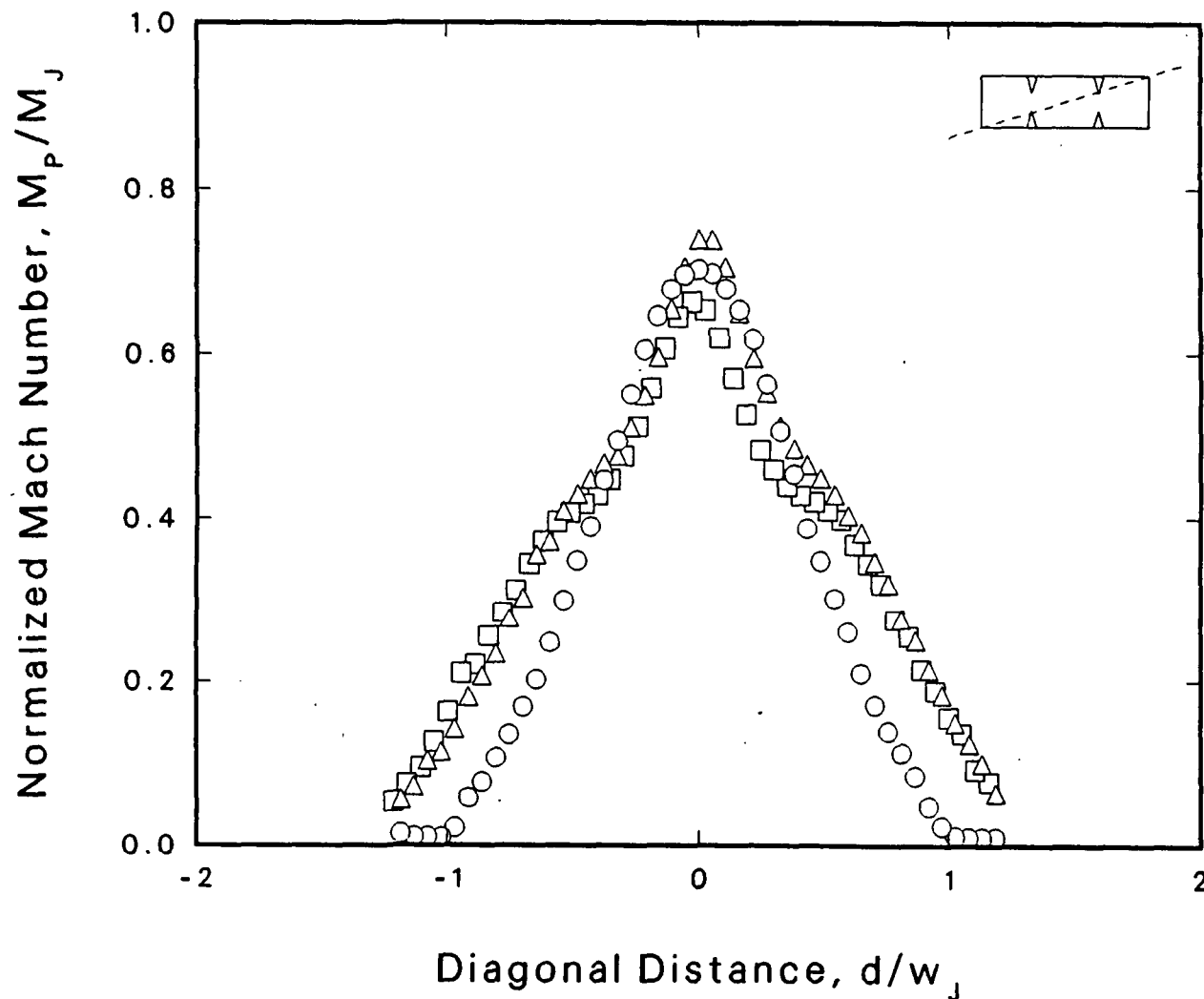
Sym	○	Δ	□
File	TAB203T	TAB237T	TAB246T
Config	0-0	VII-A	VII-B
M_j	1.151	1.147	1.148
T_{TJ}/T_A	0.99	0.99	0.98
T_{TJ} , K	283.1	281.3	281.3
U_j , mps	345.3	343.2	343.5
Re_{De}	1.842	1.845	1.827
Re_h	0.816	0.817	0.809
Re_w	3.260	3.265	3.235
p_A , kPa	98.375	98.273	97.156
T_A , K	284.7	284.6	287.0
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	0.0	0.0	0.0

Figure B.83 Configuration VII, Vertical Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



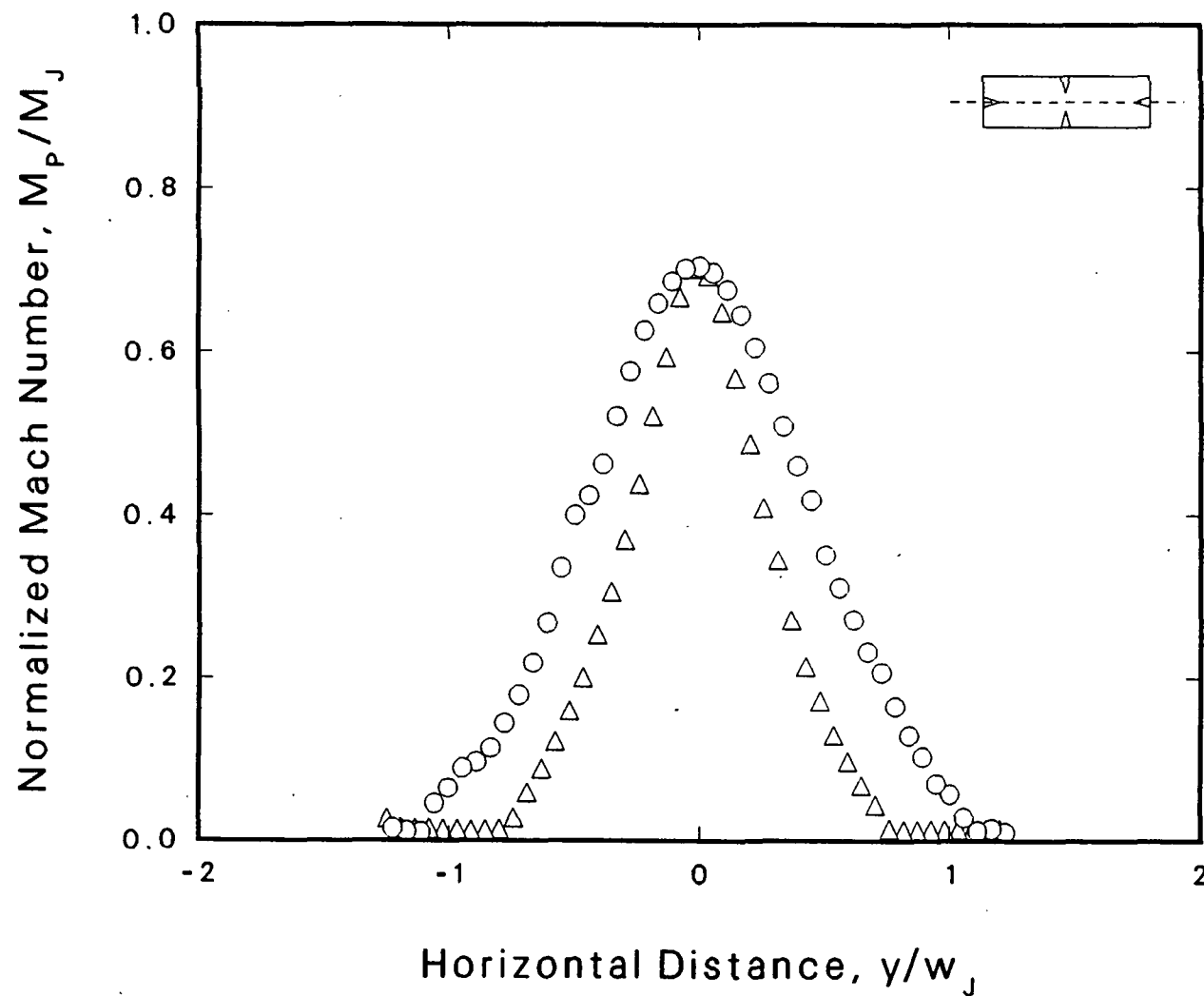
Sym	○	Δ	□
File	TAB209T	TAB255T	TAB262T
Config	0-0	VII-A	VII-B
M _j	1.144	1.148	1.147
T _{TJ} /T _A	0.99	0.99	0.99
T _{TJ} , K	281.8	281.2	280.7
U _j , mps	342.9	343.5	343.0
Re _{De}	1.849	1.851	1.863
Re _h	0.819	0.820	0.825
Re _w	3.374	3.377	3.399
p _A , kPa	99.086	98.341	98.849
T _A , K	283.4	284.4	282.4
De _j , mm	50.8	50.8	50.8
X/De _j	9.00	9.00	9.00
Z/h _j	0.00	0.00	0.00
ΔY, mm	0.0	0.0	2.0

Figure B.84 Configuration VII, Diagonal Mach Number Profile,
X/De=9, Mj=1.15, Tj/T0=1, θ=-14°



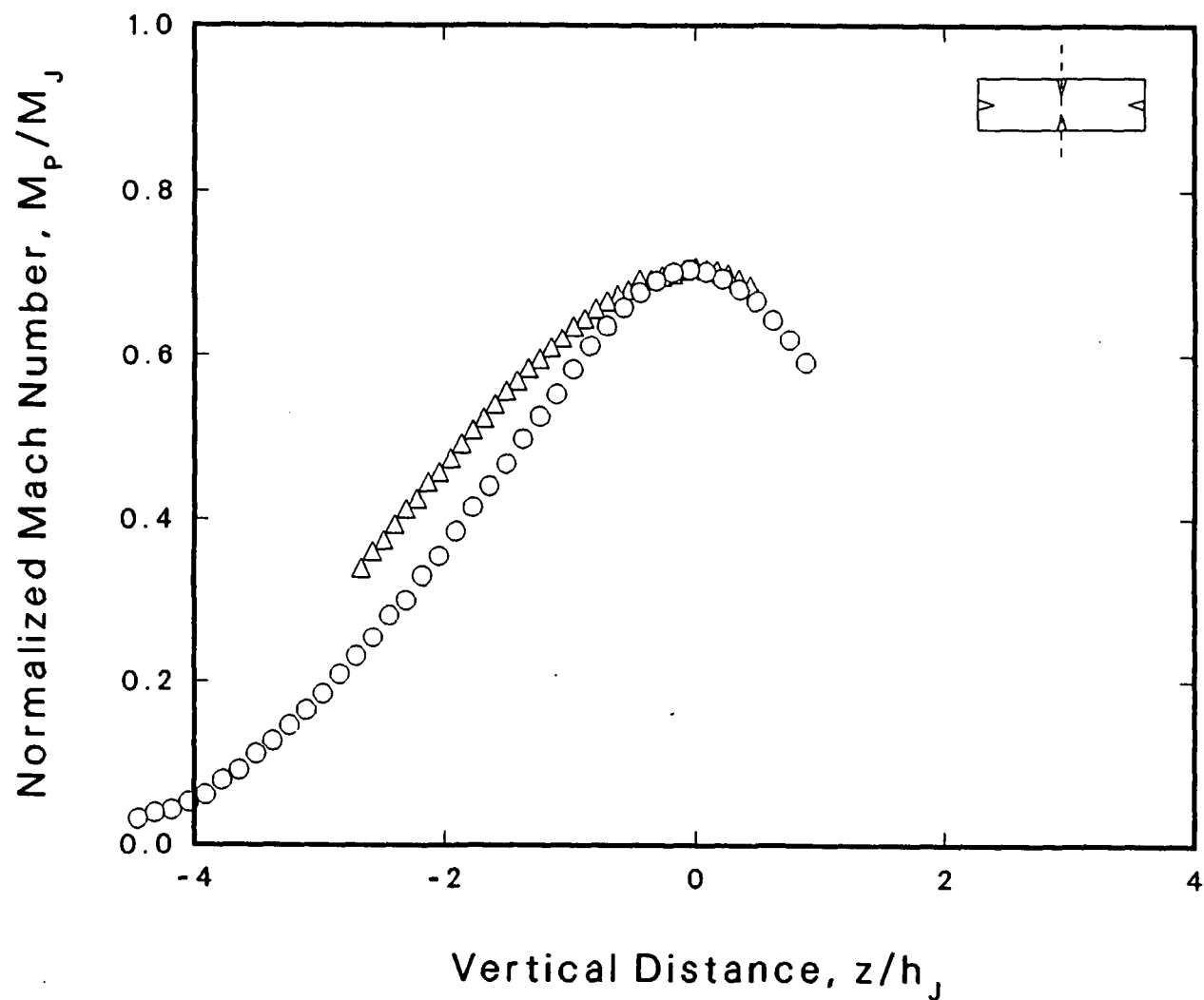
Sym	○	△	□
File	TAB221T	TAB233T	TAB235T
Config	0-0	VII-A	VII-B
M_j	1.147	1.145	1.149
T_{TJ}/T_A	0.98	1.01	1.00
T_{TJ} , K	282.3	280.3	280.4
U_j , mps	344.0	342.3	343.1
Re_{De}	1.844	1.856	1.858
Re_h	0.817	0.822	0.823
Re_w	3.364	3.387	3.389
p_A , kPa	98.578	98.578	98.239
T_A , K	289.5	278.3	280.4
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	2.6

Figure B.85 Configuration VII, Diagonal Mach Number Profile,
 $X/D_e=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$



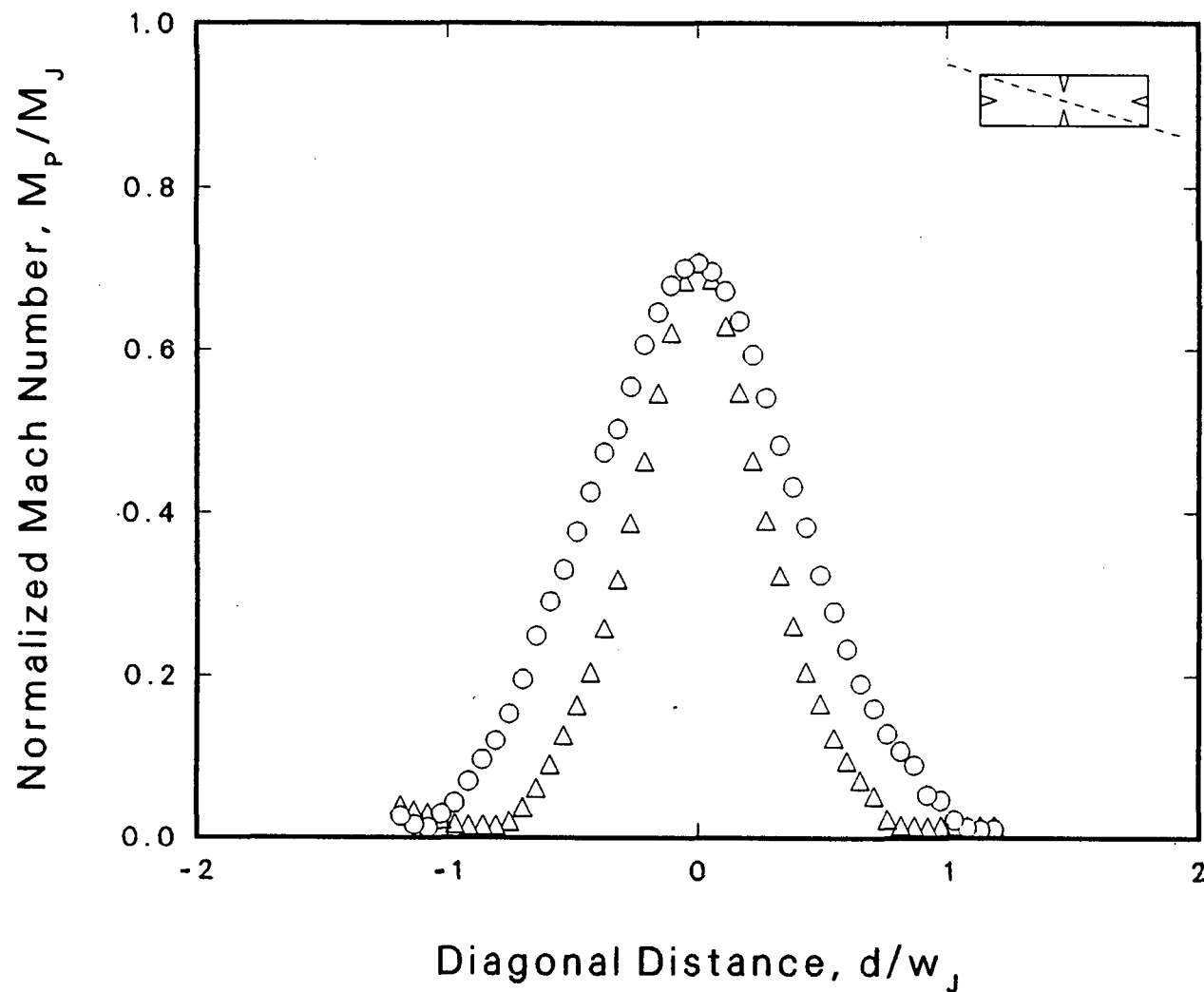
Sym	O	Δ
File	TAB185T	TAB278T
Config	0-0	V-C
M_j	1.148	1.147
T_{Tj}/T_A	1.01	1.00
T_{Tj} , K	283.3	279.0
U_j , mps	344.7	341.8
Re_{De}	1.831	1.870
Re_h	0.811	0.828
Re_w	3.241	3.311
p_A , kPa	98.273	98.578
T_A , K	280.4	280.2
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	0.0	2.0

Figure B.86 Configuration V-C, Horizontal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



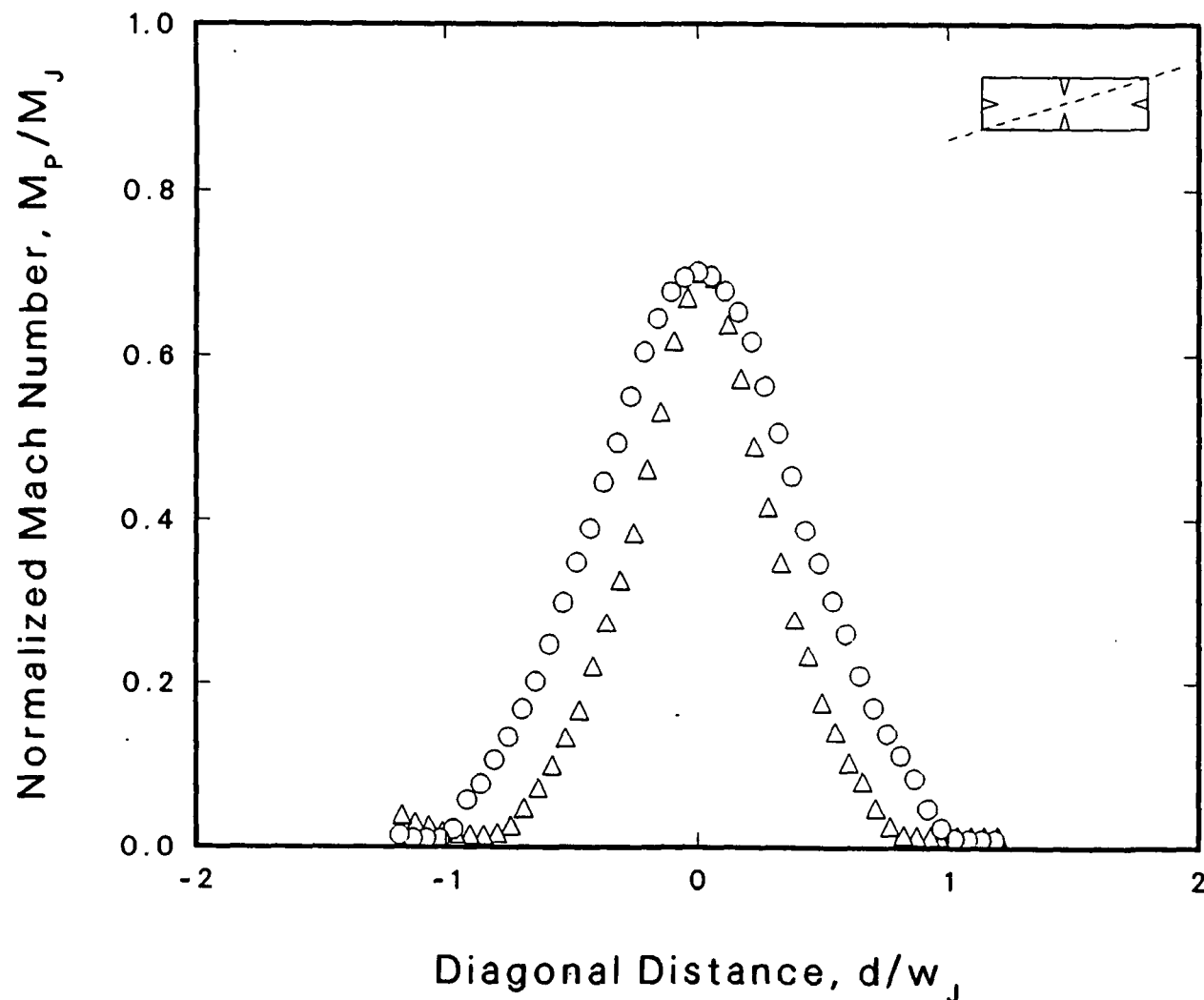
Sym	O	Δ
File	TAB203T	TAB277T
Config	0-0	V-C
M_j	1.151	1.147
T_{Tj}/T_A	0.99	1.01
T_{Tj}, K	283.1	279.0
U_j, mps	345.3	341.8
Re_{De}	1.842	1.870
Re_h	0.816	0.828
Re_w	3.260	3.310
p_A, kPa	98.375	98.544
T_A, K	284.7	276.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
$\Delta Z, mm$	0.0	0.0

Figure B.87 Configuration V-C, Vertical Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$



Sym	○	△
File	TAB209T	TAB259T
Config	0-0	V-C
M_j	1.144	1.148
T_{Tj}/T_A	0.99	0.99
T_{Tj} , K	281.8	281.4
U_j , mps	342.9	343.4
Re_{De}	1.849	1.850
Re_h	0.819	0.820
Re_w	3.374	3.376
p_A , kPa	99.086	98.476
T_A , K	283.4	284.0
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
ΔY , mm	0.0	0.0

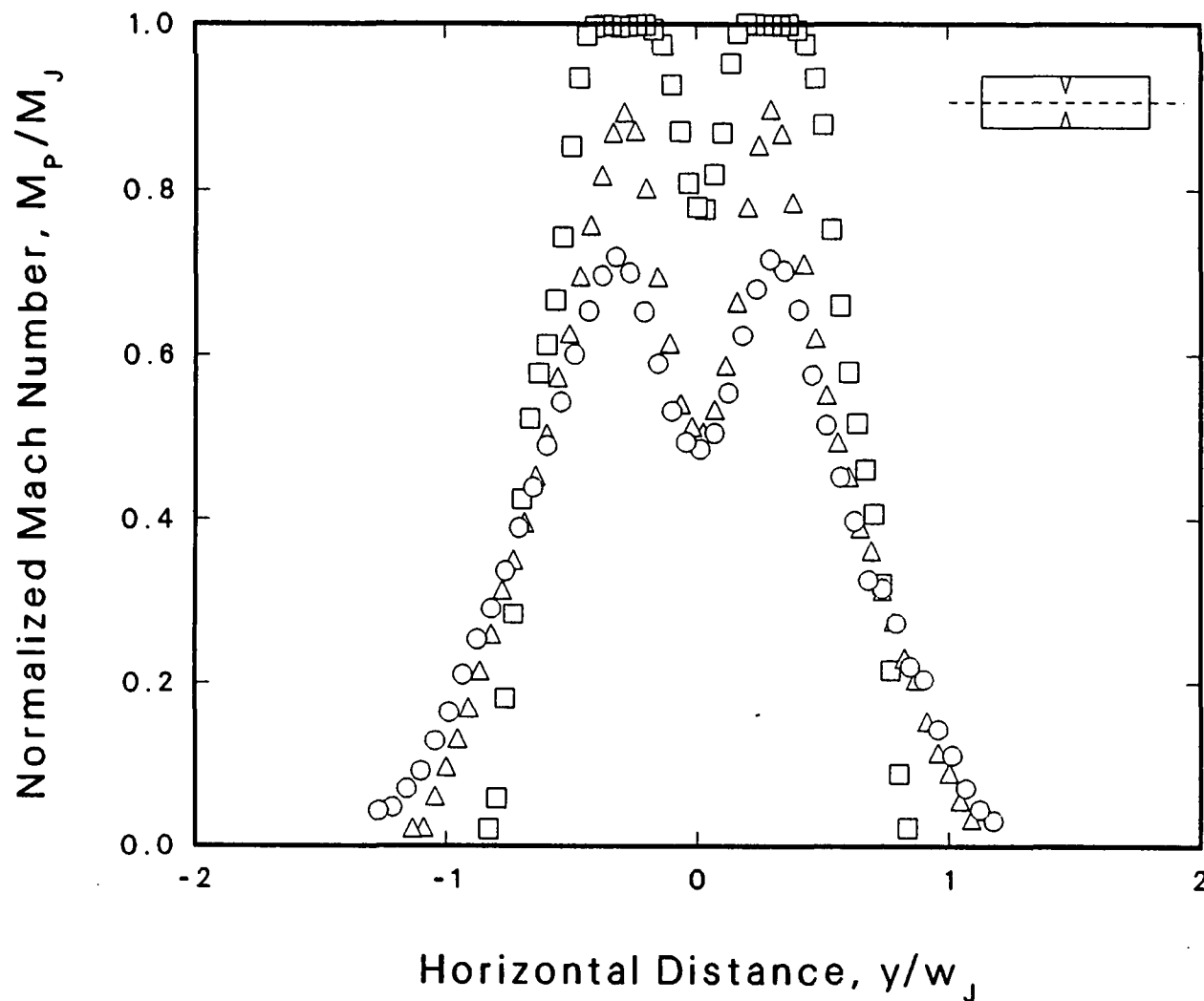
Figure B.88 Configuration V-C, Diagonal Mach Number Profile,
 $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=-14^\circ$



Sym	○	△
File	TAB221T	TAB266T
Config	0-0	V-C
M_j	1.147	1.147
T_{Tj}/T_A	0.98	1.01
T_{Tj}, K	282.3	279.3
U_j, mps	344.0	342.1
Re_{De}	1.844	1.871
Re_h	0.817	0.829
Re_w	3.364	3.414
p_A, kPa	98.578	98.713
T_A, K	289.5	277.1
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	-1.0

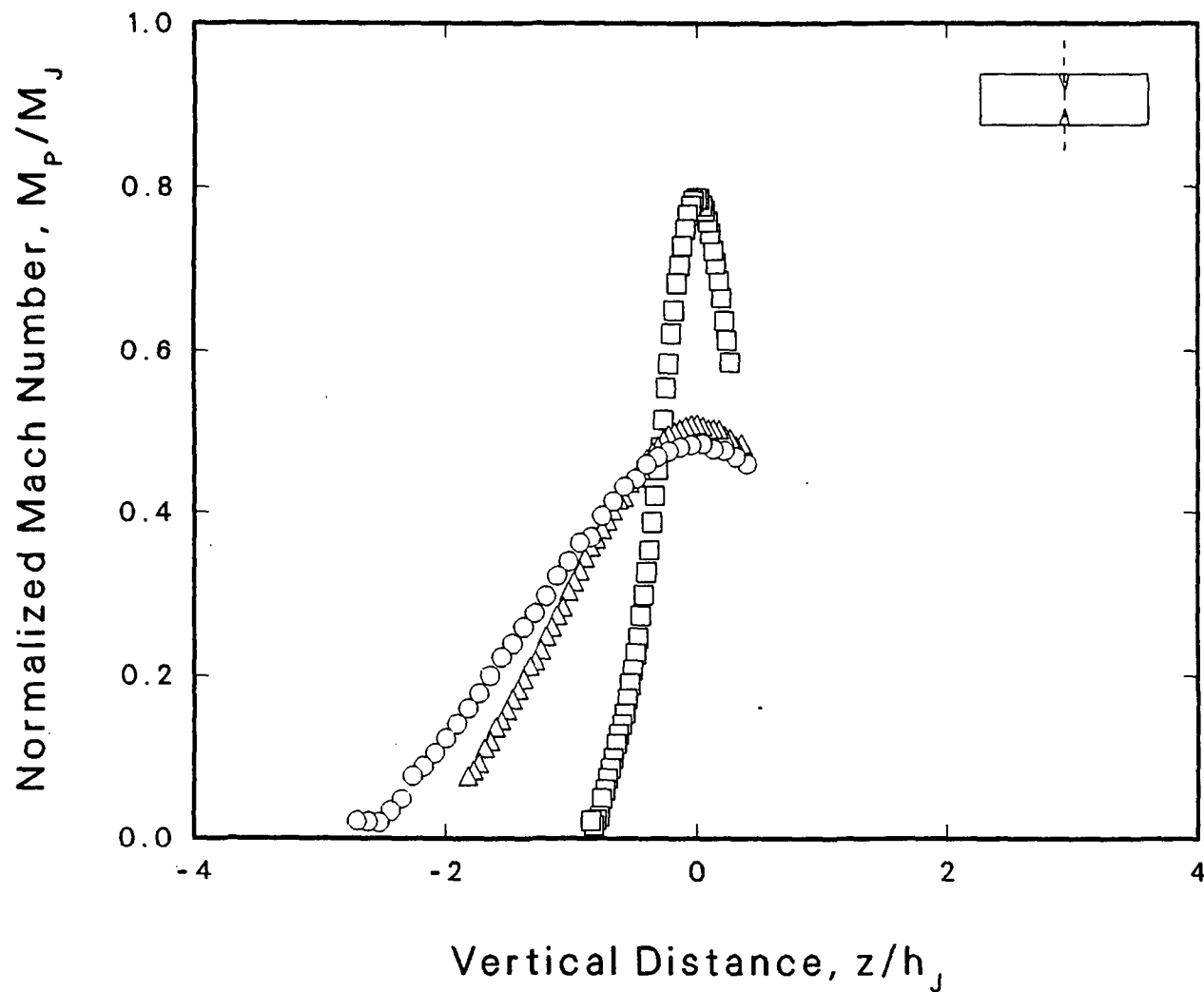
Figure B.89 Configuration V-C, Diagonal Mach Number Profile, $X/De=9$, $M_j=1.15$, $T_j/T_0=1$, $\theta=14^\circ$

B-3.4 Effect of Axial Distance on Mixing Modification



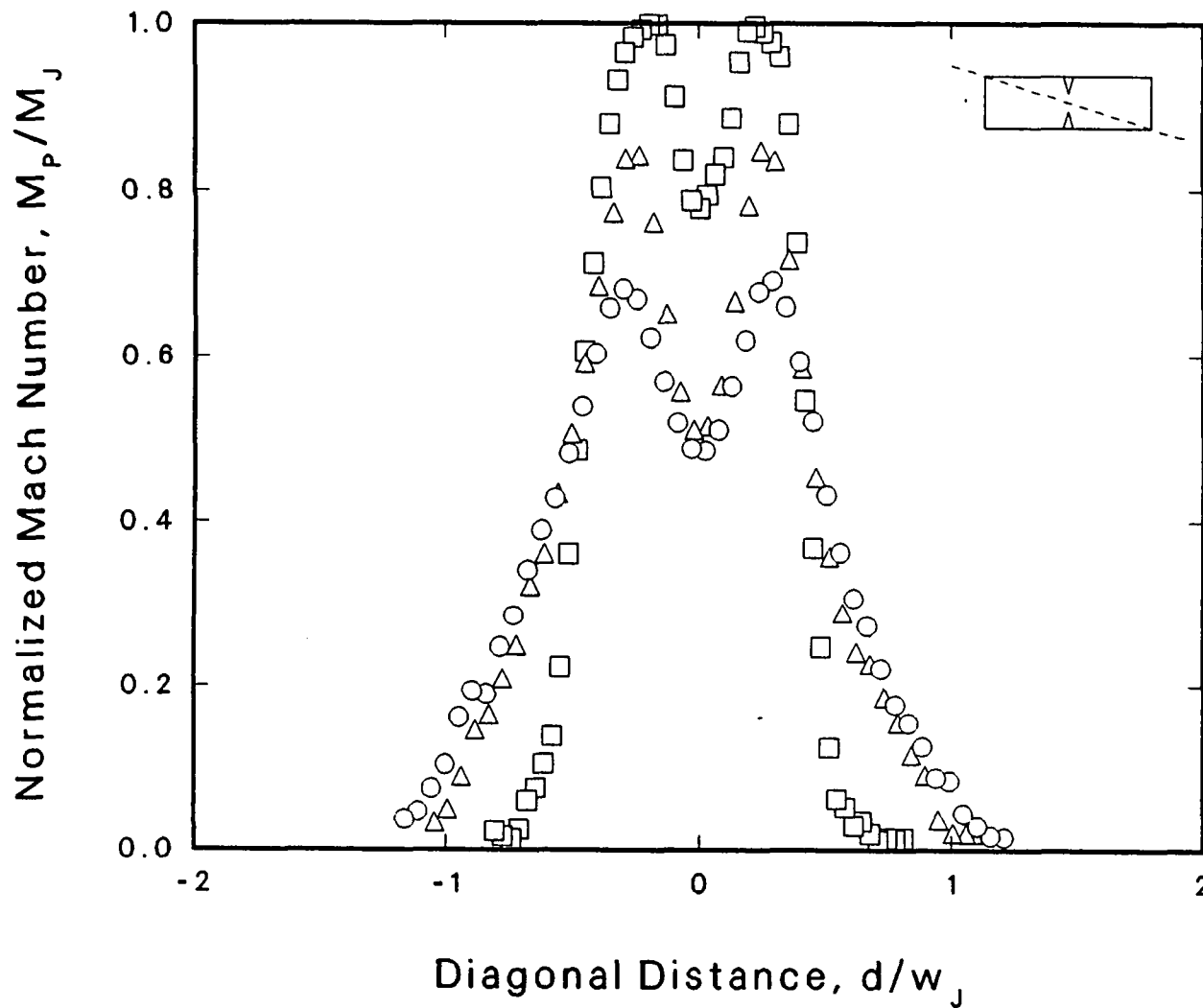
Sym	○	Δ	□
File	TAB324T	TAB321T	TAB316T
Config	I-B	I-B	I-B
M_j	0.797	0.798	0.798
T_{Tj}/T_A	1.00	0.95	0.96
T_{Tj}, K	280.7	283.2	281.9
U_j, mps	252.2	253.6	253.1
Re_{D_0}	1.119	1.104	1.104
Re_h	0.496	0.489	0.489
Re_w	1.981	1.954	1.954
p_A, kPa	99.526	99.120	98.510
T_A, K	279.5	297.2	294.5
De_j, mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	4.0	2.0	0.0

Figure B.90 Configuration I-B, Horizontal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=7,5,2$



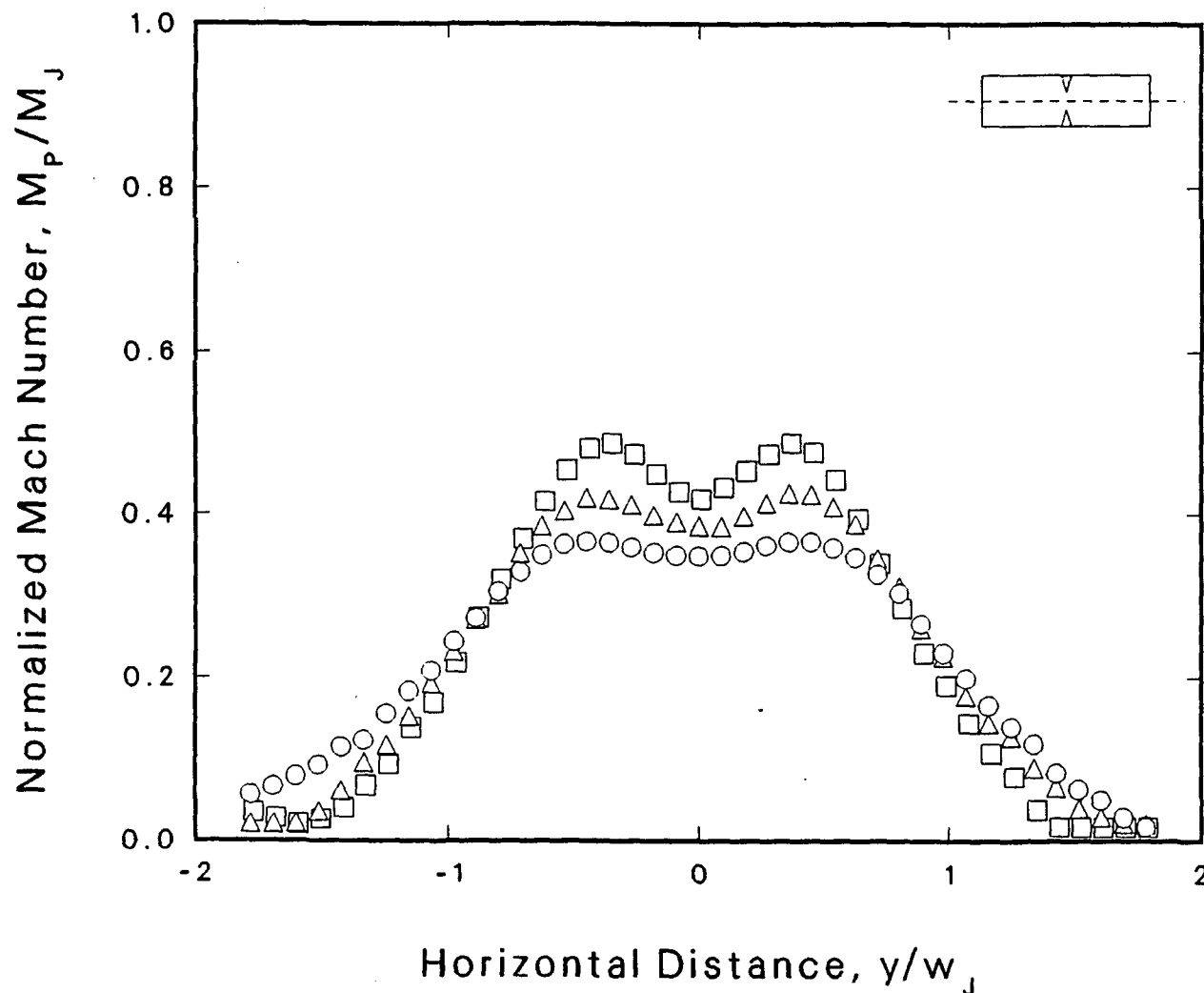
Sym	○	△	□
File	TAB325T	TAB320T	TAB317T
Config	I-B	I-B	I-B
M_j	0.796	0.798	0.797
T_{Tj}/T_A	1.01	0.97	0.97
T_{Tj}, K	280.2	282.0	281.9
U_j, mps	251.9	253.1	252.9
Re_{D_e}	1.122	1.111	1.107
Re_h	0.497	0.492	0.490
Re_w	1.986	1.966	1.960
p_A, kPa	99.560	99.221	98.916
T_A, K	278.5	291.9	292.1
De_j, mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Y/w_j	0.04	0.00	0.00
$\Delta Z, mm$	1.0	1.0	-1.0

Figure B.91 Configuration I-B, Vertical Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=7,5,2$



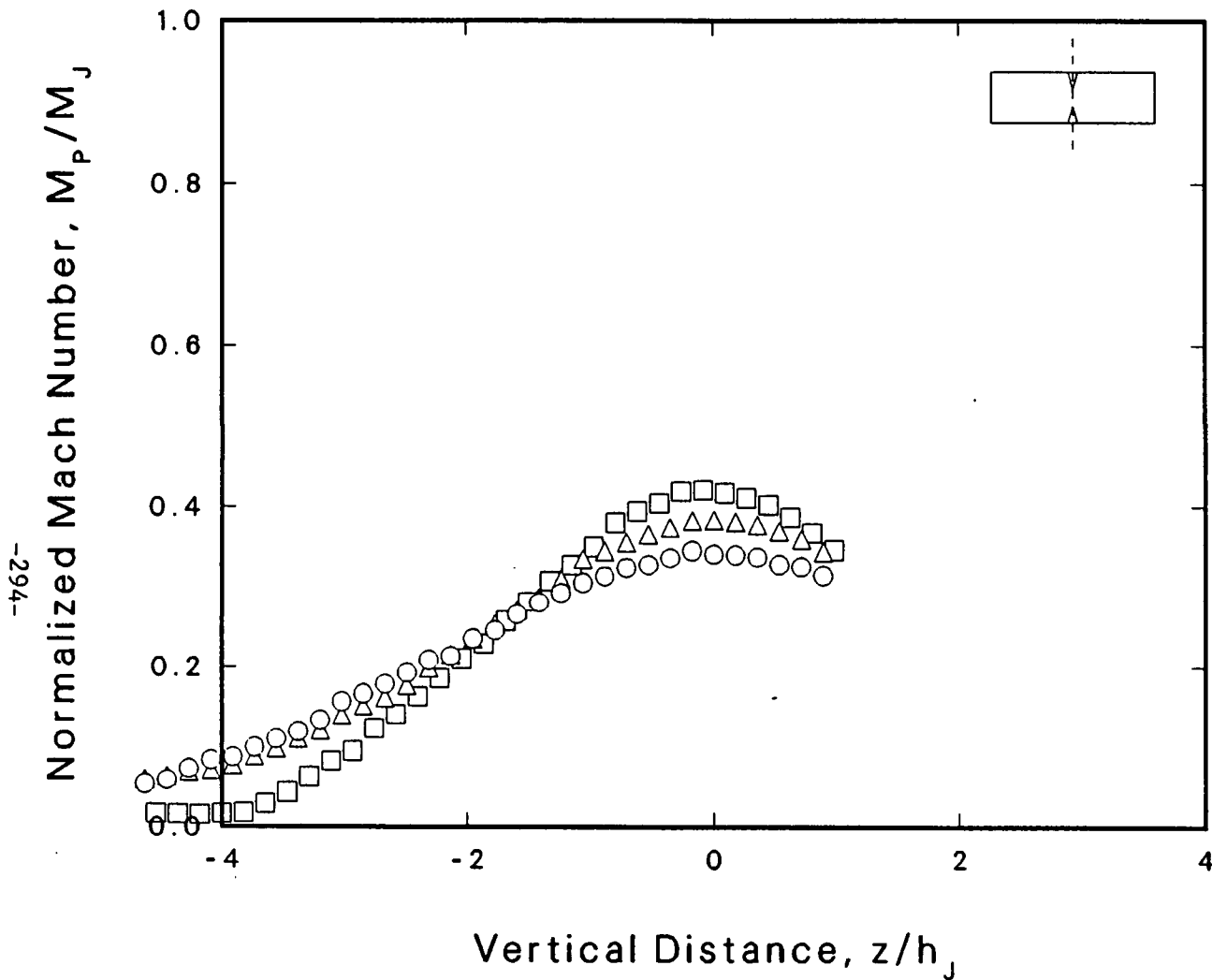
Sym	○	Δ	□
File	TAB306T	TAB308T	TAB313T
Config	I-B	I-B	I-B
M_j	0.797	0.797	0.798
T_{Tj}/T_A	1.01	1.01	1.01
T_{Tj} , K	279.9	279.9	279.0
U_j , mps	251.9	251.8	251.7
Re_{De}	1.113	1.112	1.132
Re_h	0.493	0.493	0.502
Re_w	2.030	2.030	2.066
p_A , kPa	98.544	98.578	99.763
T_A , K	276.5	277.8	275.7
De_j , mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Z/h_j	0.00	-0.03	0.04
ΔY , mm	-2.0	-3.0	0.0

Figure B.92 Configuration I-B, Diagonal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$, $X/D_e=7,5,2$



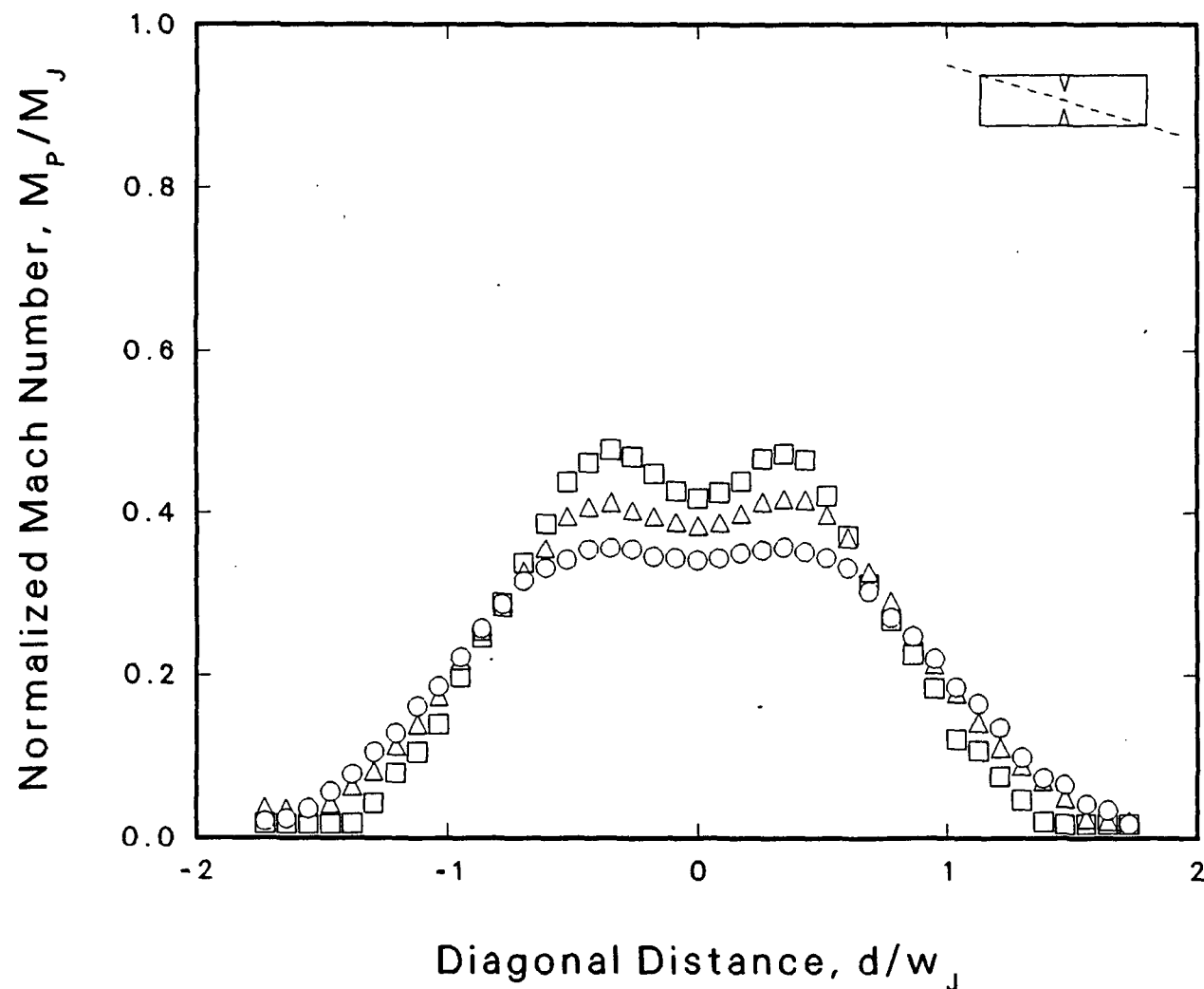
Sym	○	△	□
File	TAB283T	TAB295T	TAB298T
Config	I-B	I-B	I-B
M_j	0.798	0.797	0.799
T_{Tj}/T_A	0.99	0.98	0.97
T_{Tj} , K	280.0	281.4	282.6
U_j , mps	252.2	252.6	253.6
Re_{De}	1.112	1.098	1.099
Re_h	0.493	0.486	0.487
Re_w	1.969	1.944	1.945
p_A , kPa	98.442	97.968	98.273
T_A , K	281.8	287.3	292.7
De_j , mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	-1.0

Figure B.93 Configuration I-B, Horizontal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/De=15,13,11$



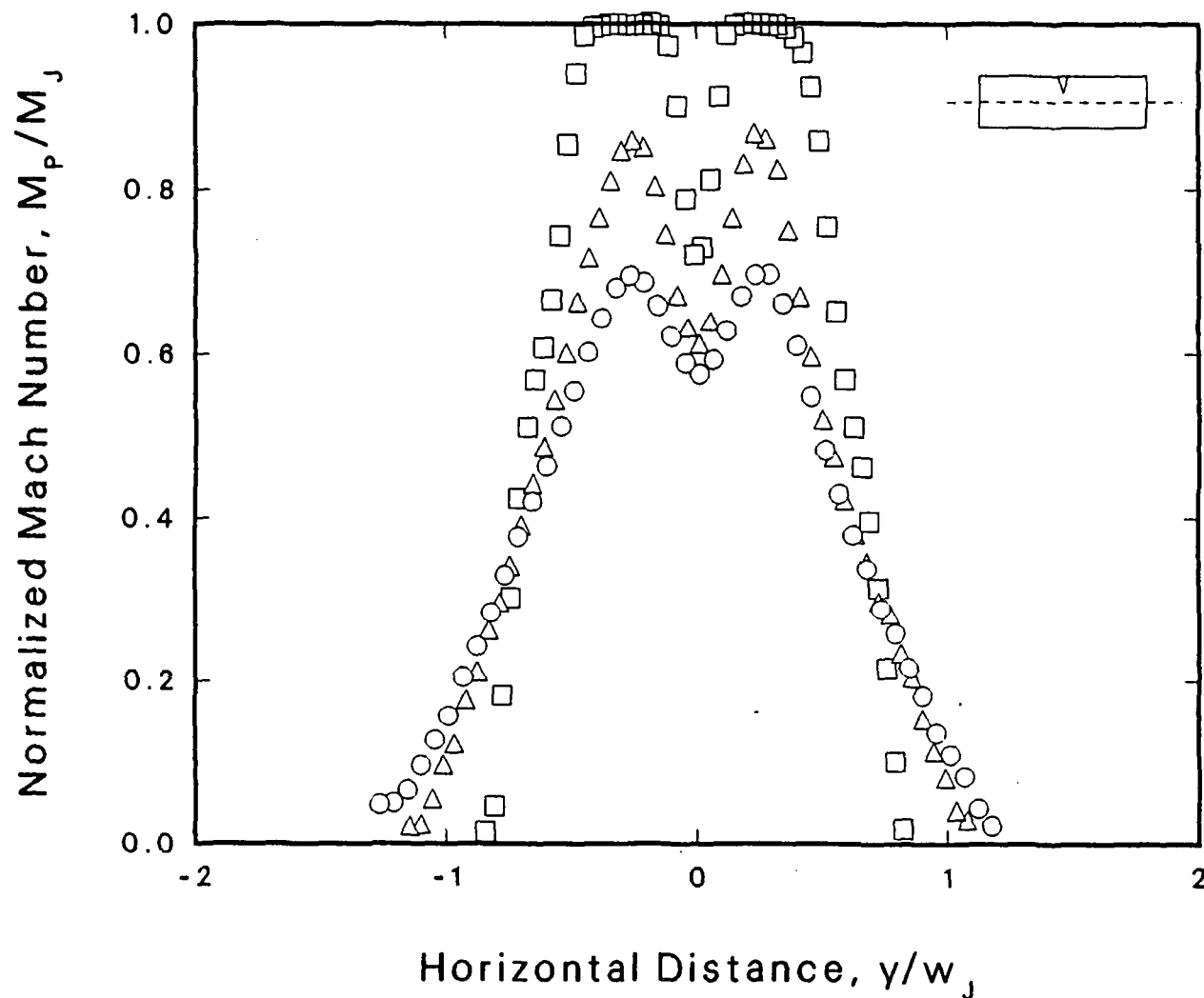
Sym	○	△	□
File	TAB284T	TAB294T	TAB299T
Config	I-B	I-B	I-B
M_j	0.797	0.798	0.800
T_{TJ}/T_A	1.00	0.99	0.96
T_{TJ} , K	279.6	281.0	282.4
U_j , mps	251.7	252.5	253.9
Re_{De}	1.113	1.102	1.101
Re_h	0.493	0.488	0.488
Re_w	1.971	1.950	1.950
p_A , kPa	98.510	97.968	98.205
T_A , K	280.7	284.2	292.9
De_j , mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	0.0	0.0	-2.0

Figure B.94 Configuration I-B, Vertical Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=15,13,11$



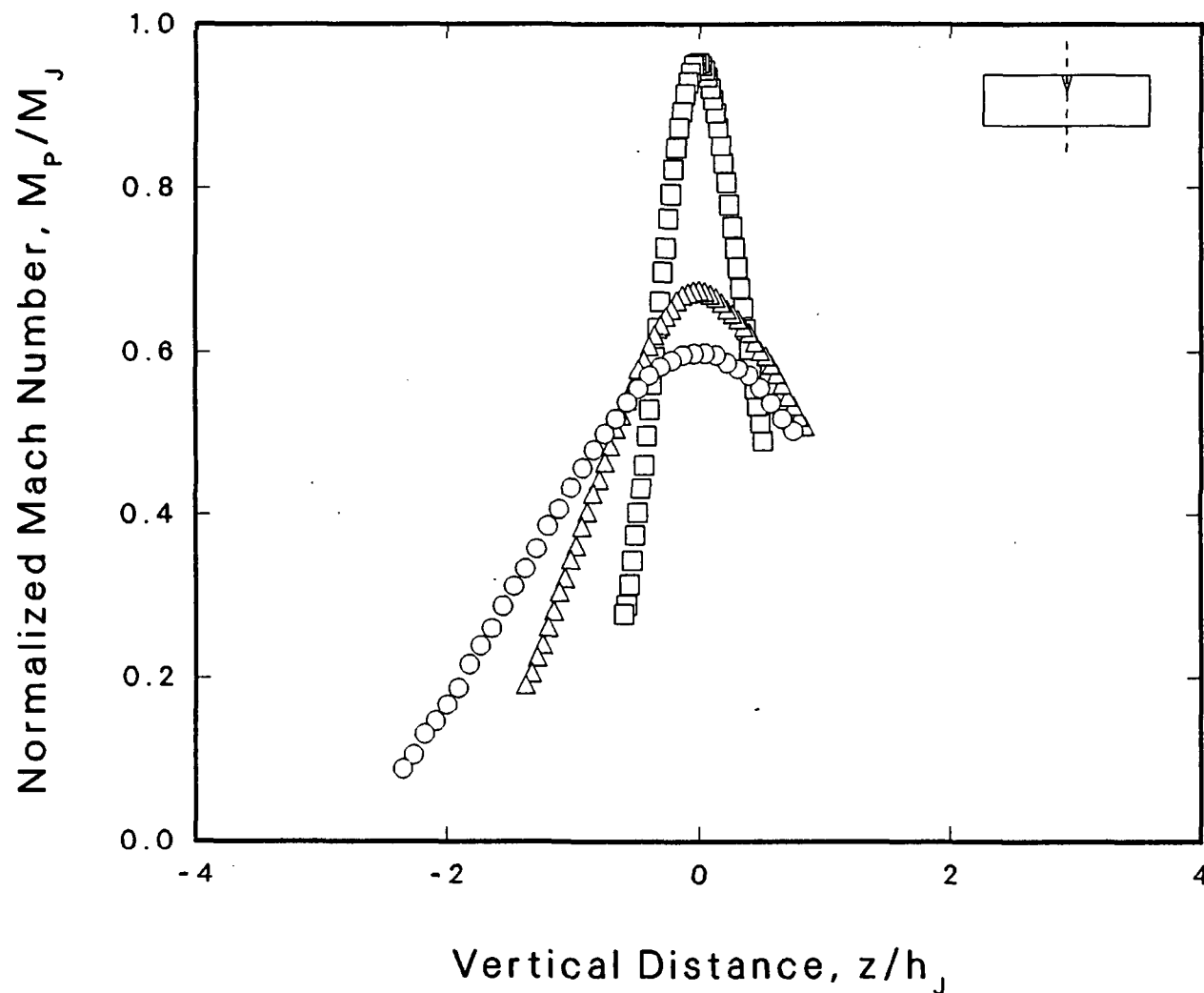
Sym	○	Δ	□
File	TAB290T	TAB291T	TAB305T
Config	I-B	I-B	I-B
M_j	0.798	0.797	0.796
T_{Tj}/T_A	0.98	1.00	1.00
T_{Tj}, K	280.8	280.0	281.0
U_j, mps	252.5	252.0	252.1
Re_{De}	1.101	1.107	1.105
Re_h	0.488	0.490	0.489
Re_w	2.009	2.021	2.016
p_A, kPa	97.833	98.070	98.510
T_A, K	285.9	278.7	282.1
De_j, mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	0.0

Figure B.95 Configuration I-B, Diagonal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$, $X/D_e=15,13,11$



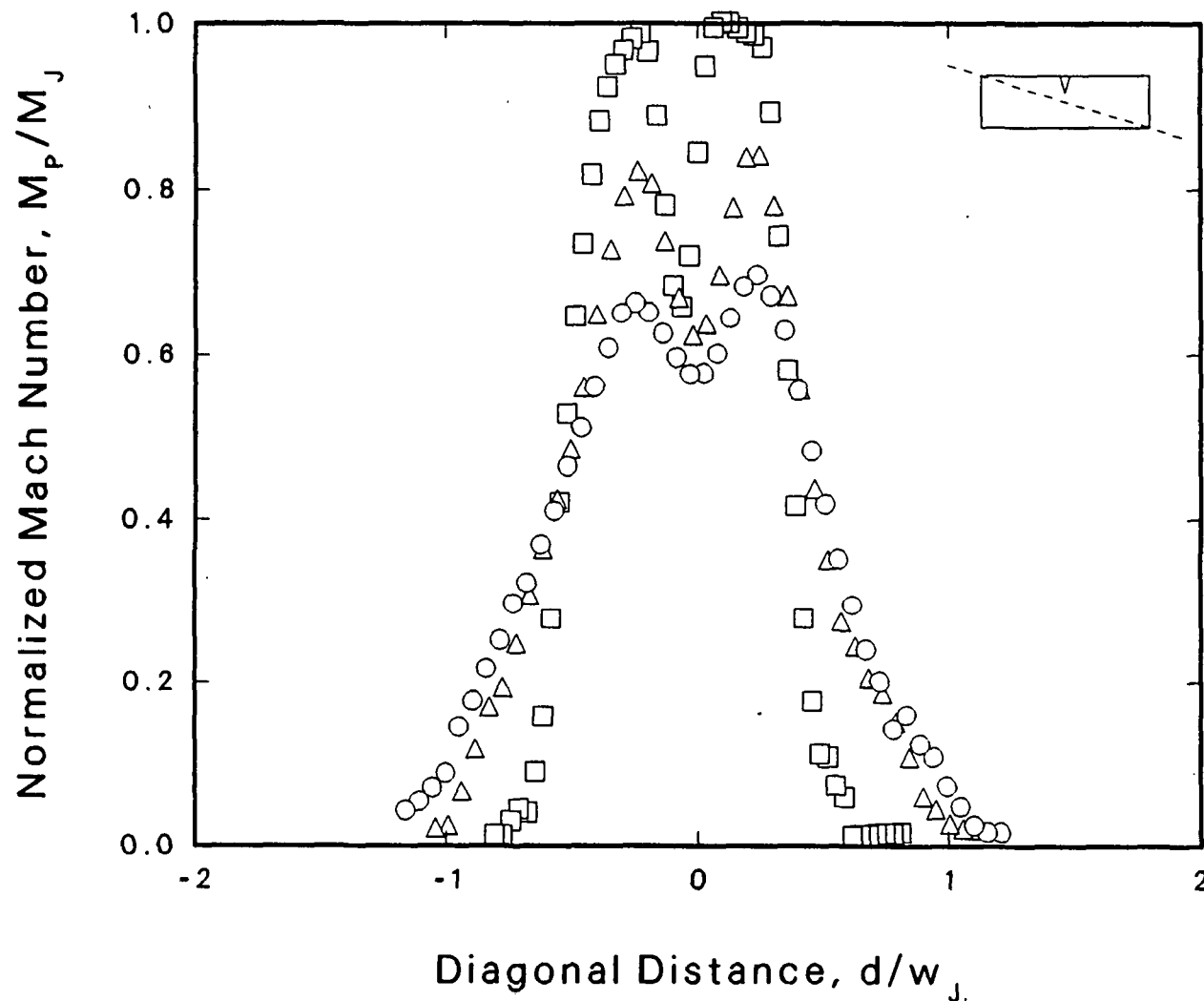
Sym	○	Δ	□
File	TAB327T	TAB322T	TAB319T
Config	III-B	III-B	III-B
M_j	0.797	0.799	0.798
T_{TJ}/T_A	1.01	0.95	0.95
T_{TJ} , K	279.3	282.6	282.2
U_j , mps	251.6	253.6	253.3
Re_{De}	1.114	1.106	1.106
Re_h	0.493	0.490	0.490
Re_w	1.971	1.959	1.958
p_A , kPa	98.375	99.018	98.815
T_A , K	276.4	297.9	296.1
De_j , mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	4.0	3.0	1.0

Figure B.96 Configuration III-B, Horizontal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=7,5,2$



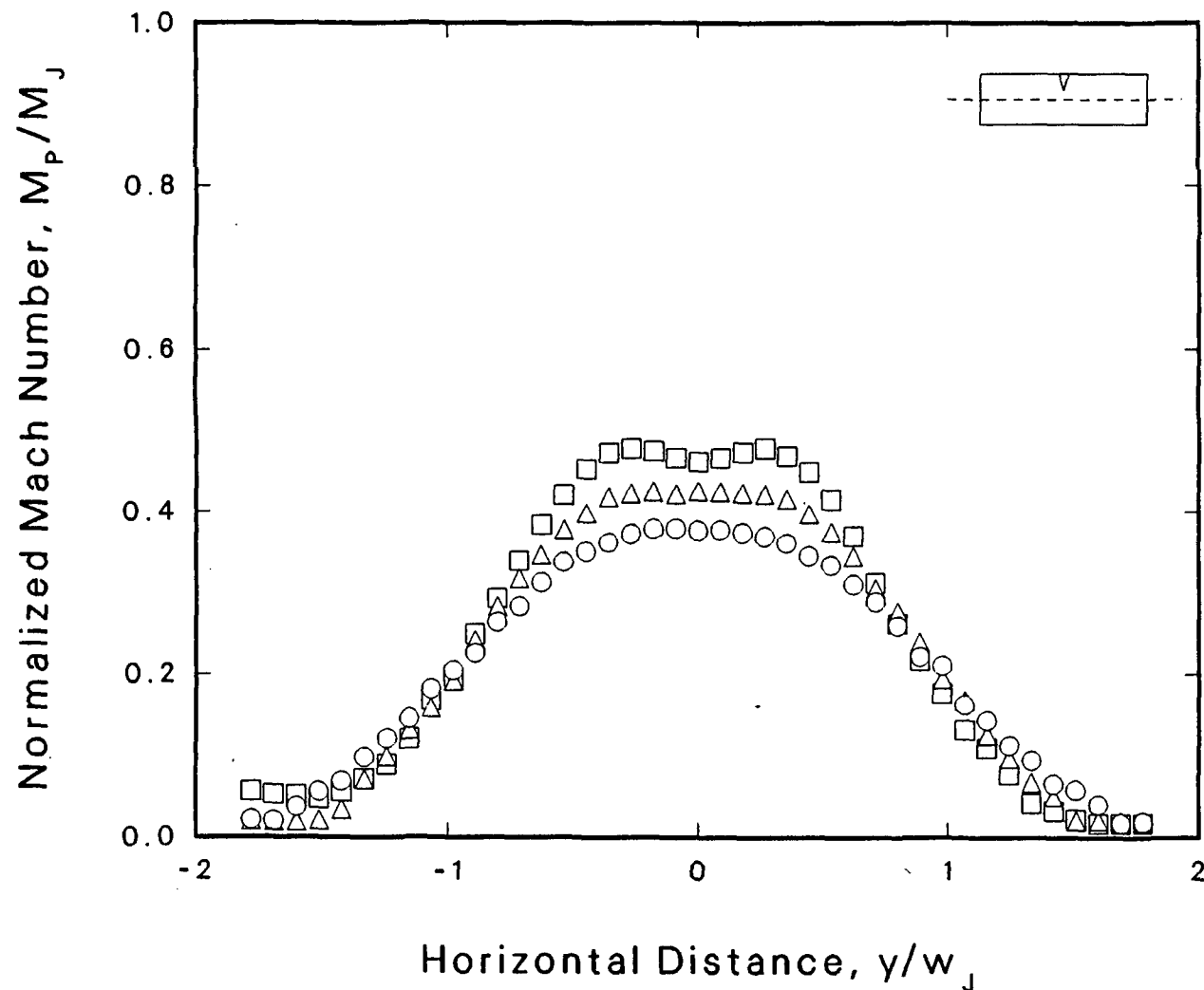
Sym	○	△	□
File	TAB326T	TAB323T	TAB318T
Config	III-B	III-B	III-B
M_j	0.797	0.799	0.798
T_{TJ}/T_A	1.01	0.95	0.95
T_{TJ} , K	279.9	282.7	282.7
U_j , mps	251.9	253.7	253.4
Re_{De}	1.125	1.106	1.104
Re_h	0.498	0.490	0.489
Re_w	1.991	1.958	1.954
p_A , kPa	99.628	98.984	98.883
T_A , K	277.8	298.9	296.5
De_j , mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Y/w_j	0.04	0.00	0.00
ΔZ , mm	-7.0	-9.0	-6.5

Figure B.97 Configuration III-B, Vertical Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=7,5,2$



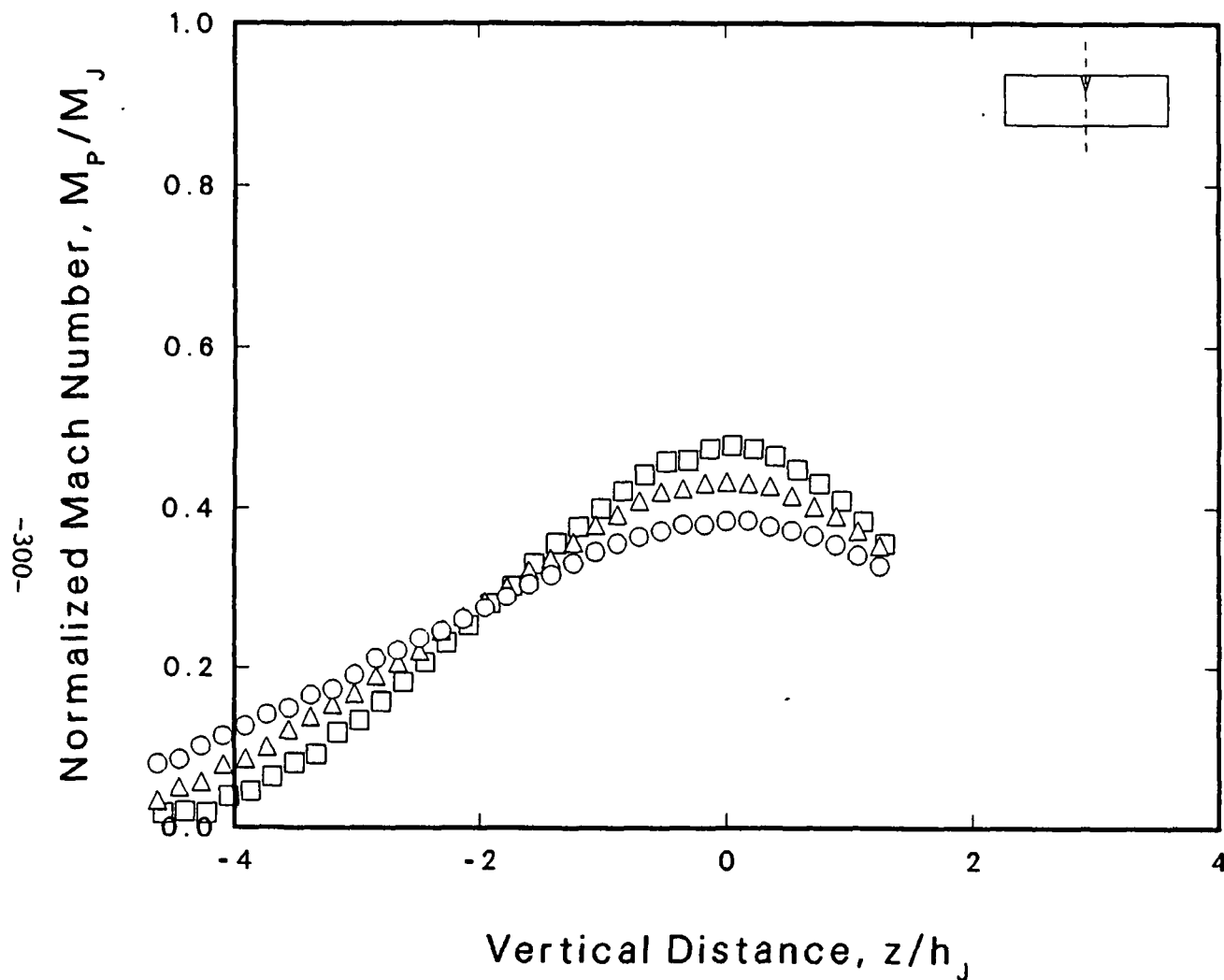
Sym	○	Δ	□
File	TAB307T	TAB309T	TAB311T
Config	III-B	III-B	III-B
M_j	0.797	0.797	0.797
T_{Tj}/T_A	1.01	1.00	1.01
T_{Tj}, K	279.7	280.4	279.4
U_j, mps	251.8	252.0	251.6
Re_{De}	1.114	1.109	1.123
Re_h	0.494	0.491	0.497
Re_w	2.033	2.024	2.048
p_A, kPa	98.612	98.510	99.221
T_A, K	276.1	279.2	277.3
De_j, mm	50.8	50.8	50.8
X/De_j	7.00	5.00	2.00
Z/h_j	0.00	-0.03	0.00
$\Delta Y, mm$	-2.0	-3.0	0.0

Figure B.98 Configuration III-B, Diagonal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$, $X/De=7,5,2$



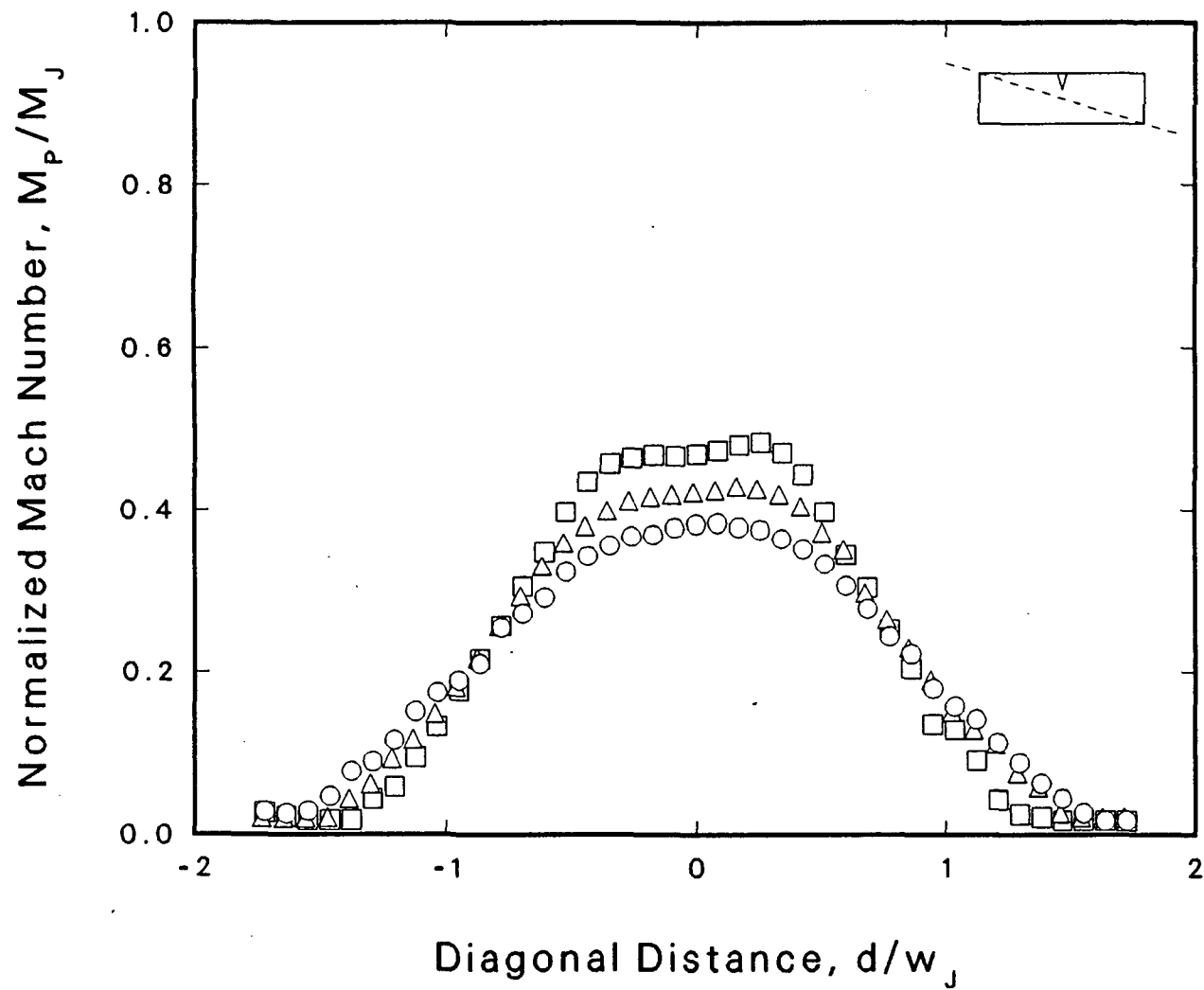
Sym	○	Δ	□
File	TAB286T	TAB296T	TAB301T
Config	III-B	III-B	III-B
M_j	0.796	0.798	0.797
T_{Tj}/T_A	0.99	0.97	0.98
T_{Tj} , K	279.4	282.2	282.1
U_j , mps	251.5	253.3	253.0
Re_{D_e}	1.115	1.095	1.099
Re_h	0.494	0.485	0.487
Re_w	1.974	1.938	1.946
p_A , kPa	98.612	97.799	98.307
T_A , K	281.5	292.1	288.1
D_{e_j} , mm	50.8	50.8	50.8
X/D_{e_j}	15.00	13.00	11.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure B.99 Configuration III-B, Horizontal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=15,13,11$



Sym	○	△	□
File	TAB285T	TAB297T	TAB300T
Config	III-B	III-B	III-B
M_j	0.797	0.798	0.799
T_{TJ}/T_A	0.99	0.96	0.96
T_{TJ} , K	279.5	282.2	282.2
U_j , mps	251.7	253.2	253.4
Re_{D_e}	1.115	1.094	1.100
Re_h	0.494	0.485	0.487
Re_w	1.974	1.936	1.948
p_A , kPa	98.578	97.765	98.239
T_A , K	281.0	293.7	293.0
De_j , mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	-8.0	-8.0	-9.0

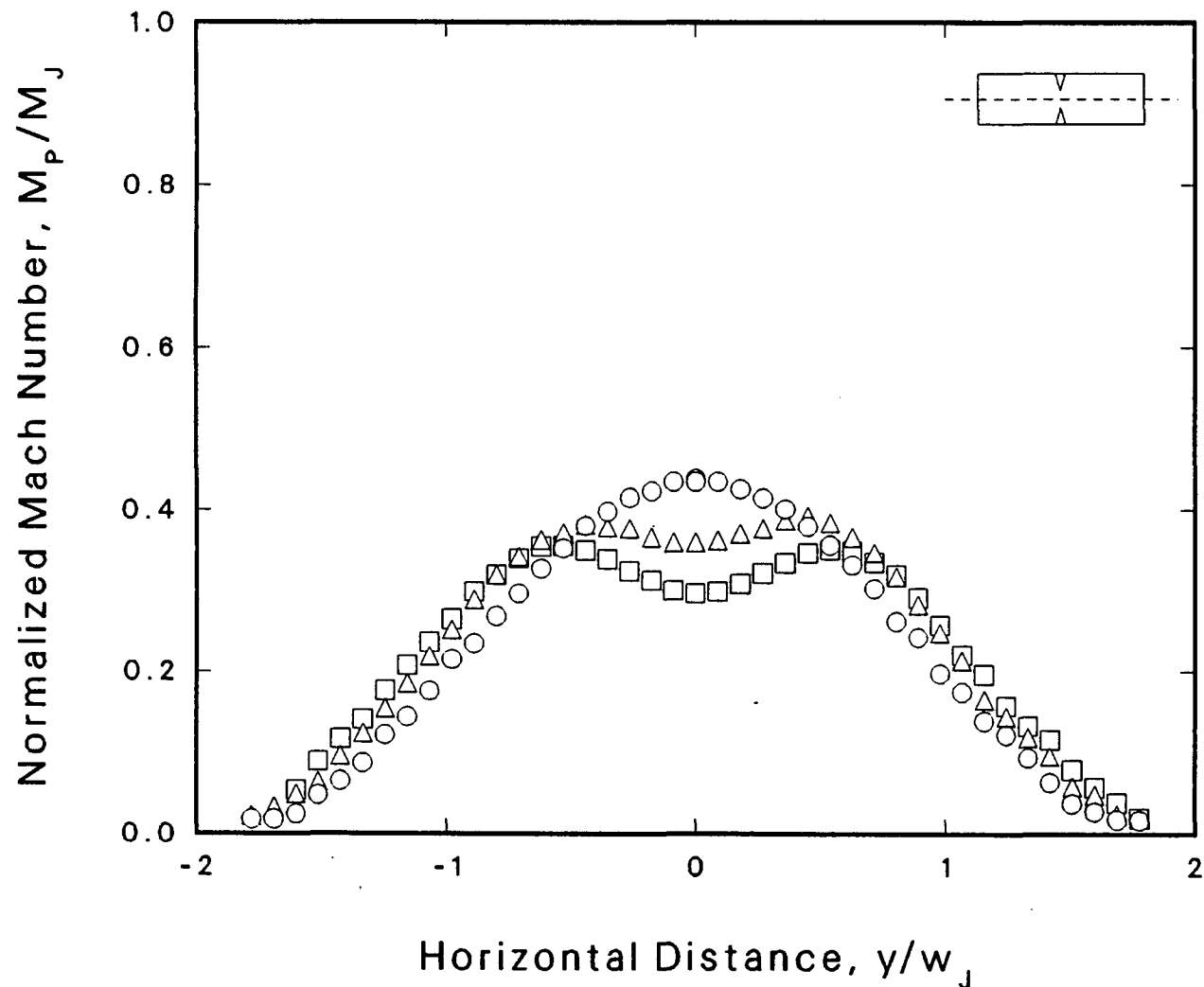
Figure B.100 Configuration III-B, Vertical Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $X/D_e=15,13,11$



Sym	○	Δ	□
File	TAB289T	TAB292T	TAB304T
Config	III-B	III-B	III-B
M_j	0.798	0.797	0.796
T_{Tj}/T_A	0.99	1.00	1.00
T_{Tj}, K	280.7	280.1	281.0
U_j, mps	252.4	252.0	252.1
Re_{De}	1.102	1.107	1.105
Re_h	0.488	0.490	0.489
Re_w	2.010	2.019	2.016
p_A, kPa	97.799	98.070	98.510
T_A, K	284.9	281.3	281.4
De_j, mm	50.8	50.8	50.8
X/De_j	15.00	13.00	11.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	1.0	0.0

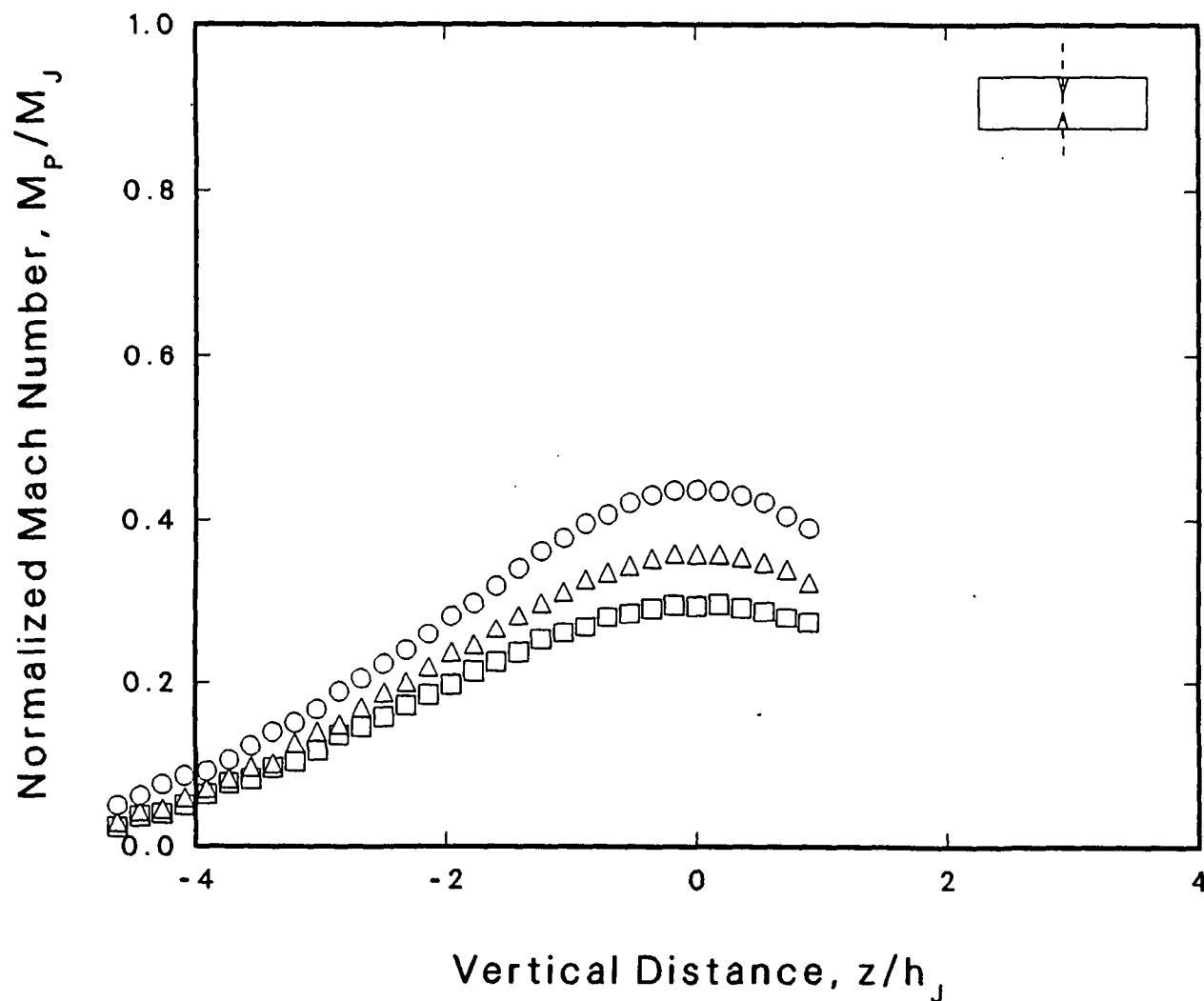
Figure B.101 Configuration III-B, Diagonal Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$, $\theta=-14^\circ$, $X/D_e=15,13,11$

B-3.5 Mixing Modification for Heated Subsonic Jets



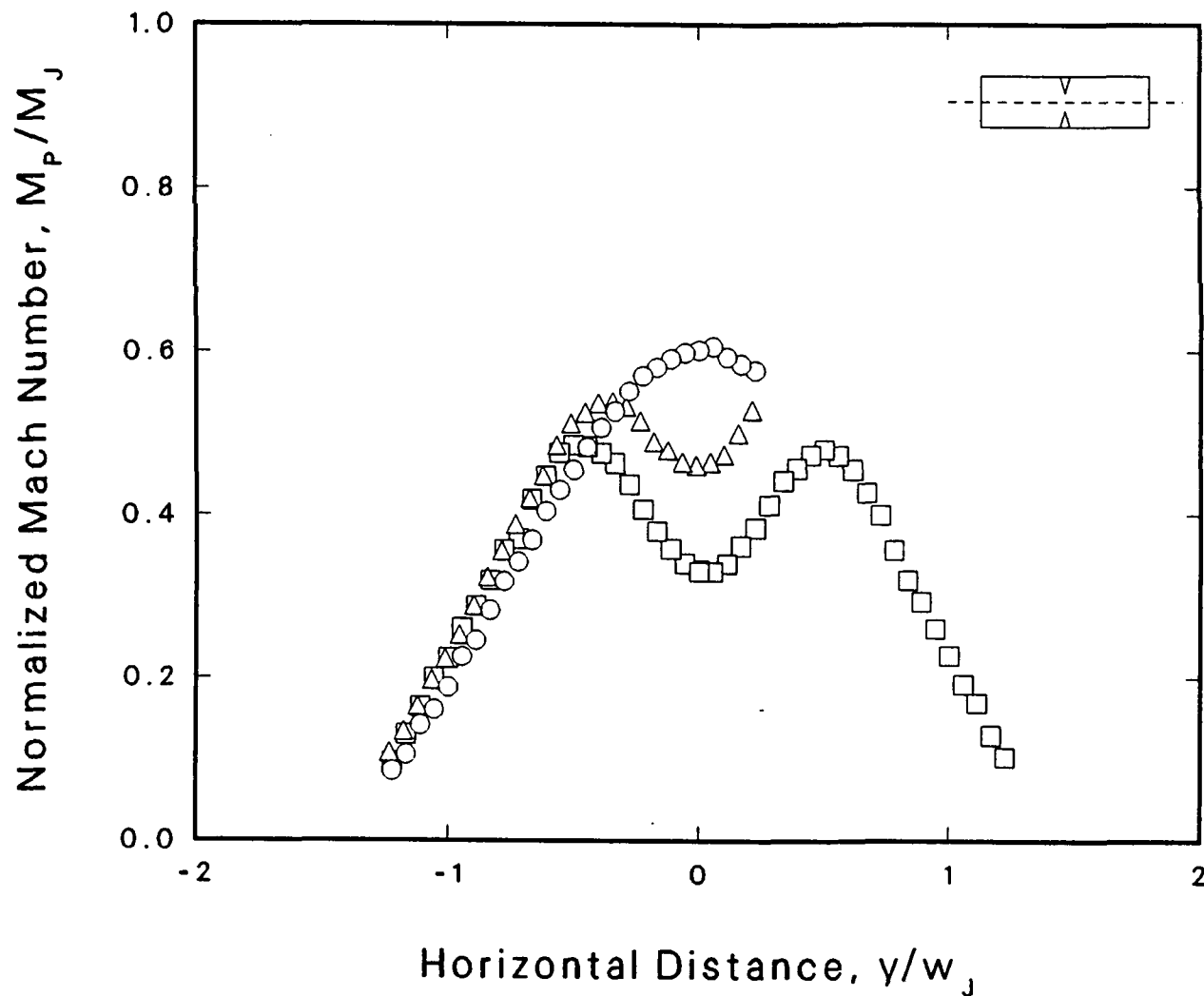
Sym	○	△	□
File	TAB356T	TAB354T	TAB357T
Config	0-0	I-B	I-C
M_j	0.804	0.805	0.803
T_{Tj}/T_A	2.29	2.29	2.31
T_{Tj} , K	652.4	652.9	654.9
U_j , mps	385.7	386.0	386.0
Re_{De}	0.388	0.388	0.385
Re_h	0.172	0.172	0.170
Re_w	0.688	0.688	0.681
p_A , kPa	97.765	97.799	97.528
T_A , K	284.4	285.1	283.7
De_j , mm	50.8	50.8	50.8
X/De_j	13.00	13.00	13.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	0.0	0.0

Figure B.102 Mixing Modification, Horizontal Mach Number Profile,
Config. I-B, I-C, $X/De=13$, $M_j=0.8$, $T_j/T_0=2.3$



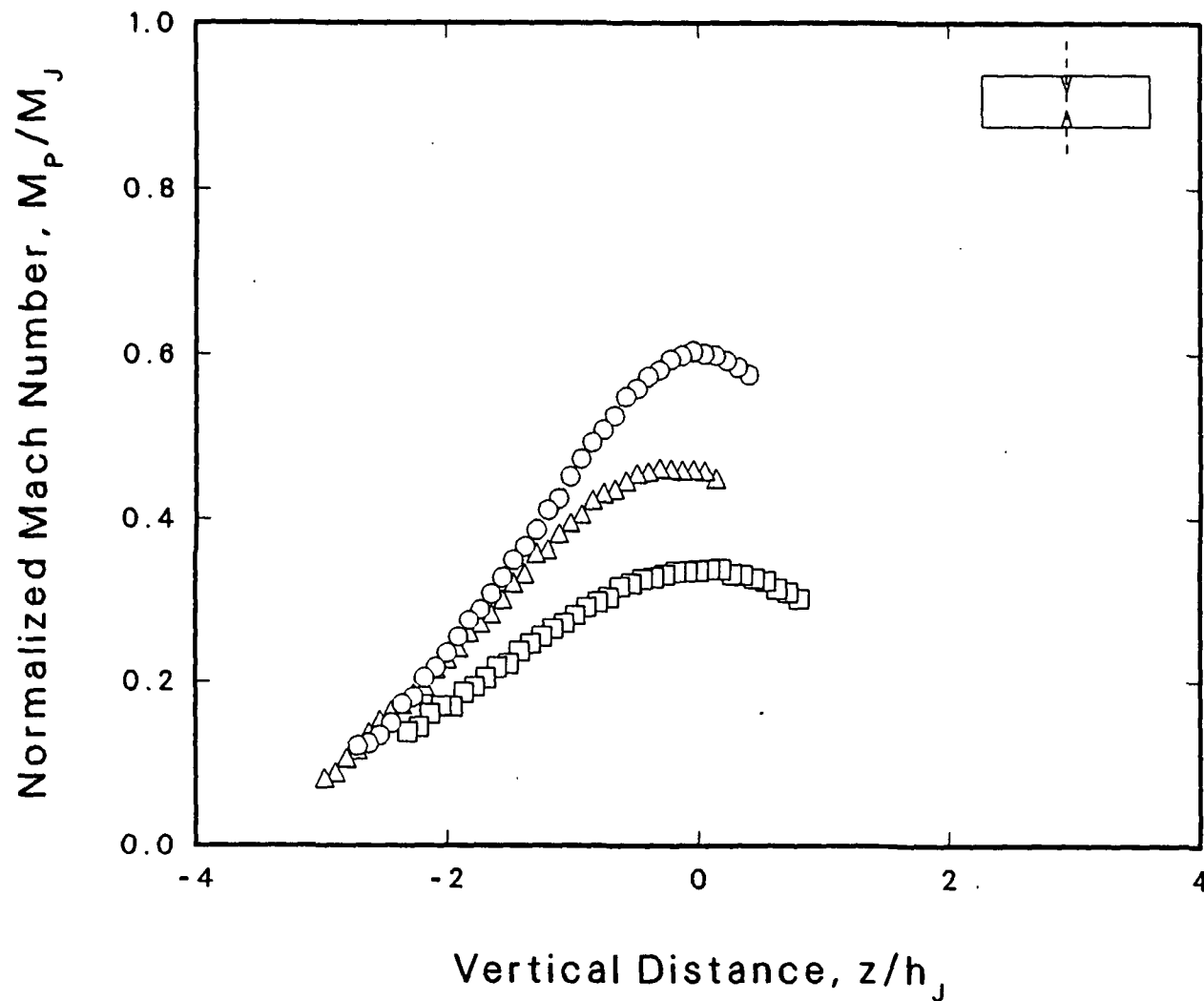
Sym	○	Δ	□
File	TAB355T	TAB353T	TAB358T
Config	0-0	I-B	I-C
M_j	0.804	0.803	0.803
T_{Tj}/T_A	2.29	2.31	2.30
T_{Tj}, K	651.5	659.7	652.9
U_j, mps	385.5	387.3	385.3
Re_{D_e}	0.389	0.384	0.386
Re_h	0.172	0.170	0.171
Re_w	0.689	0.680	0.683
p_A, kPa	97.765	98.205	97.460
T_A, K	284.8	285.3	284.3
De_j, mm	50.8	50.8	50.8
X/De_j	13.00	13.00	13.00
Y/w_j	0.00	0.00	0.00
$\Delta Z, mm$	0.0	0.0	0.0

Figure B.103 Mixing Modification, Vertical Mach Number Profile,
Config. I-B, I-C, $X/D_e=13$, $M_j=0.8$, $T_j/T_0=2.3$



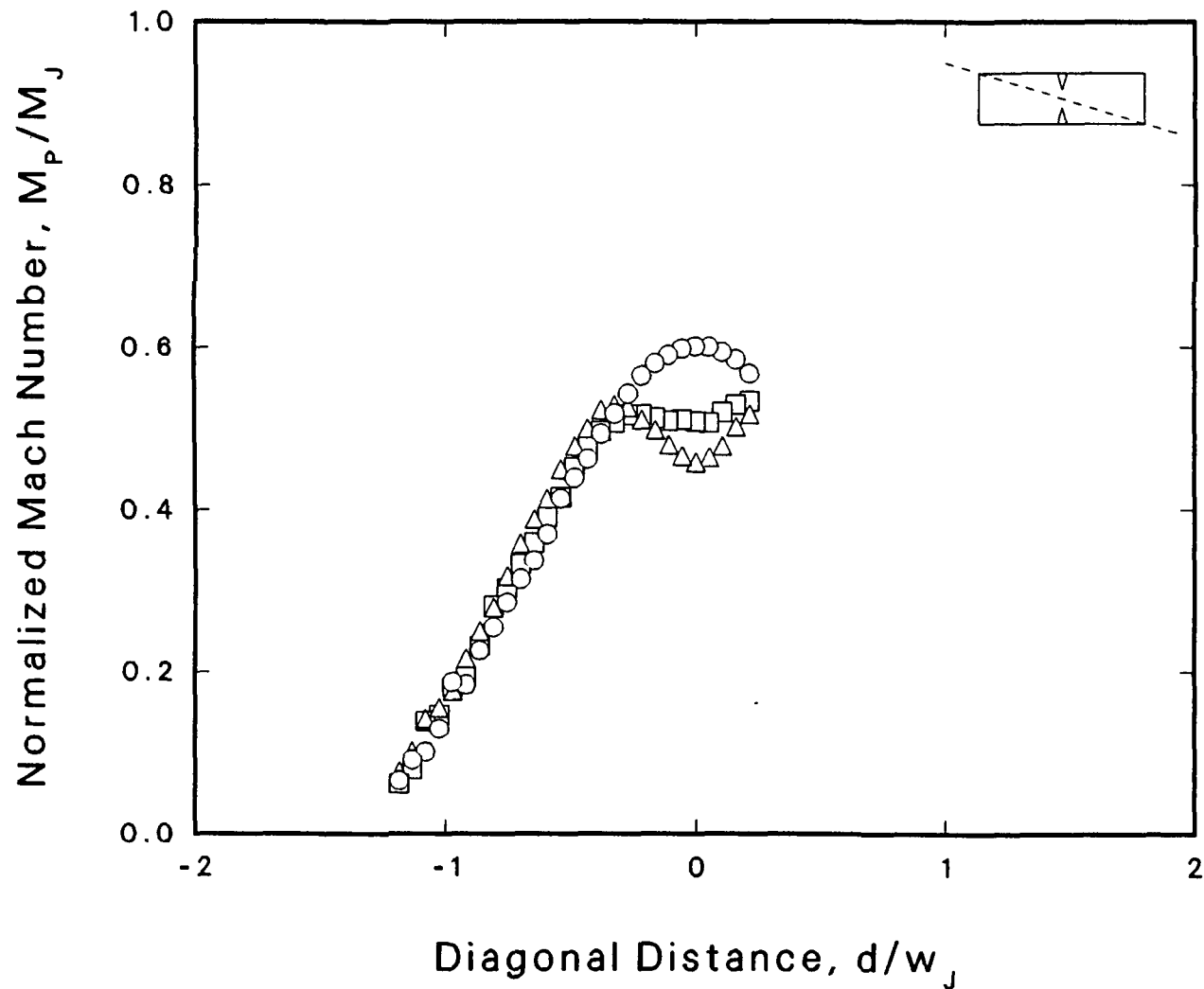
Sym	○	Δ	□
File	TAB332T	TAB333T	TAB359T
Config	0-0	I-B	I-C
M_j	0.801	0.802	0.804
T_{TJ}/T_A	2.29	2.29	2.30
T_{TJ}, K	624.8	613.9	652.1
U_j, mps	376.5	373.4	385.3
Re_{De}	0.408	0.421	0.386
Re_h	0.181	0.186	0.171
Re_w	0.723	0.745	0.683
p_A, kPa	97.968	98.815	97.189
T_A, K	272.6	268.6	283.4
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	1.0	0.0

Figure B.104 Mixing Modification, Horizontal Mach Number Profile,
Config. III-B, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$



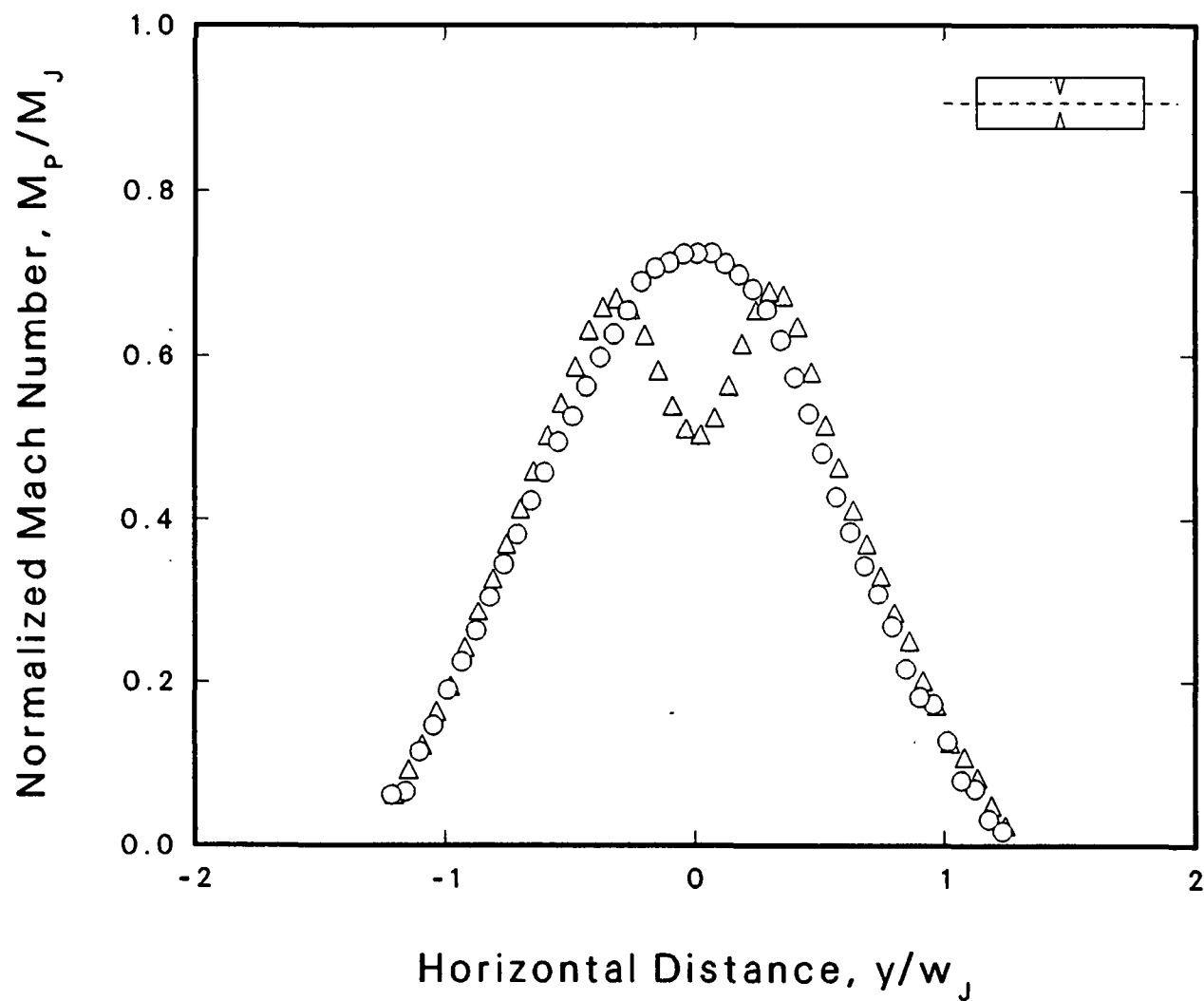
Sym	○	Δ	□
File	TAB331T	TAB334T	TAB360T
Config	0-0	I-B	I-C
M_j	0.802	0.801	0.804
T_{TJ}/T_A	2.29	2.28	2.31
T_{TJ} , K	621.9	615.2	652.2
U_j , mps	375.9	373.4	385.4
Re_{D_o}	0.411	0.419	0.386
Re_h	0.182	0.186	0.171
Re_w	0.727	0.742	0.684
p_A , kPa	98.002	98.815	97.291
T_A , K	272.0	269.8	282.8
De_j , mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	1.0	7.0	-8.0

Figure B.105 Mixing Modification, Vertical Mach Number Profile,
Config. III-B, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$



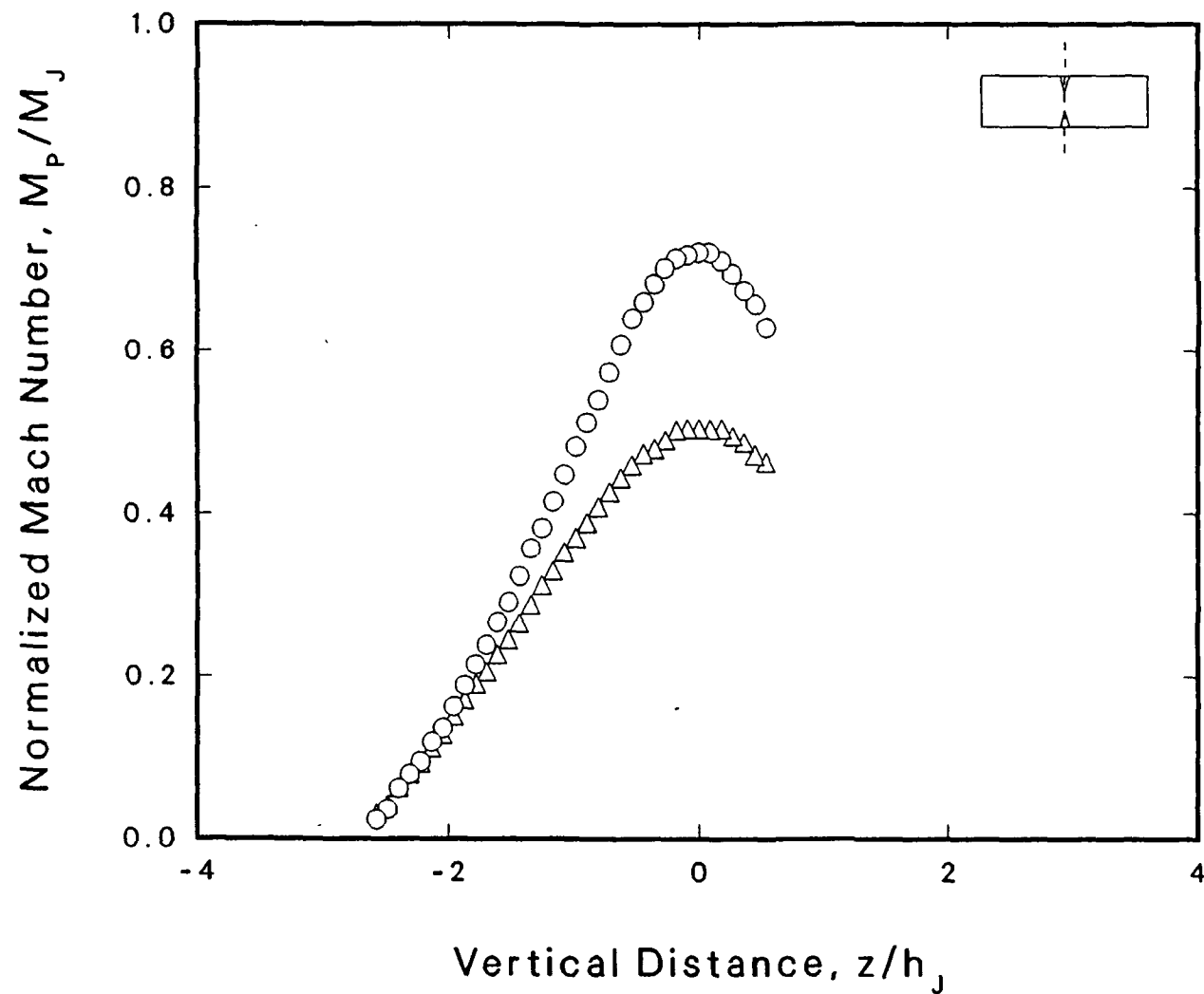
Sym	○	△	□
File	TAB346T	TAB347T	TAB348T
Config	0-0	I-B	III-B
M_j	0.803	0.805	0.804
T_{TJ}/T_A	2.29	2.29	2.30
T_{TJ}, K	641.5	661.2	664.3
U_j, mps	382.1	388.3	389.2
Re_{De}	0.395	0.382	0.379
Re_h	0.175	0.169	0.168
Re_w	0.720	0.696	0.692
p_A, kPa	97.494	97.596	97.596
T_A, K	280.5	288.3	288.8
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	0.0

Figure B.106 Mixing Modification, Diagonal Mach Number Profile,
 Config. III-B, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$, $\theta=-14^\circ$



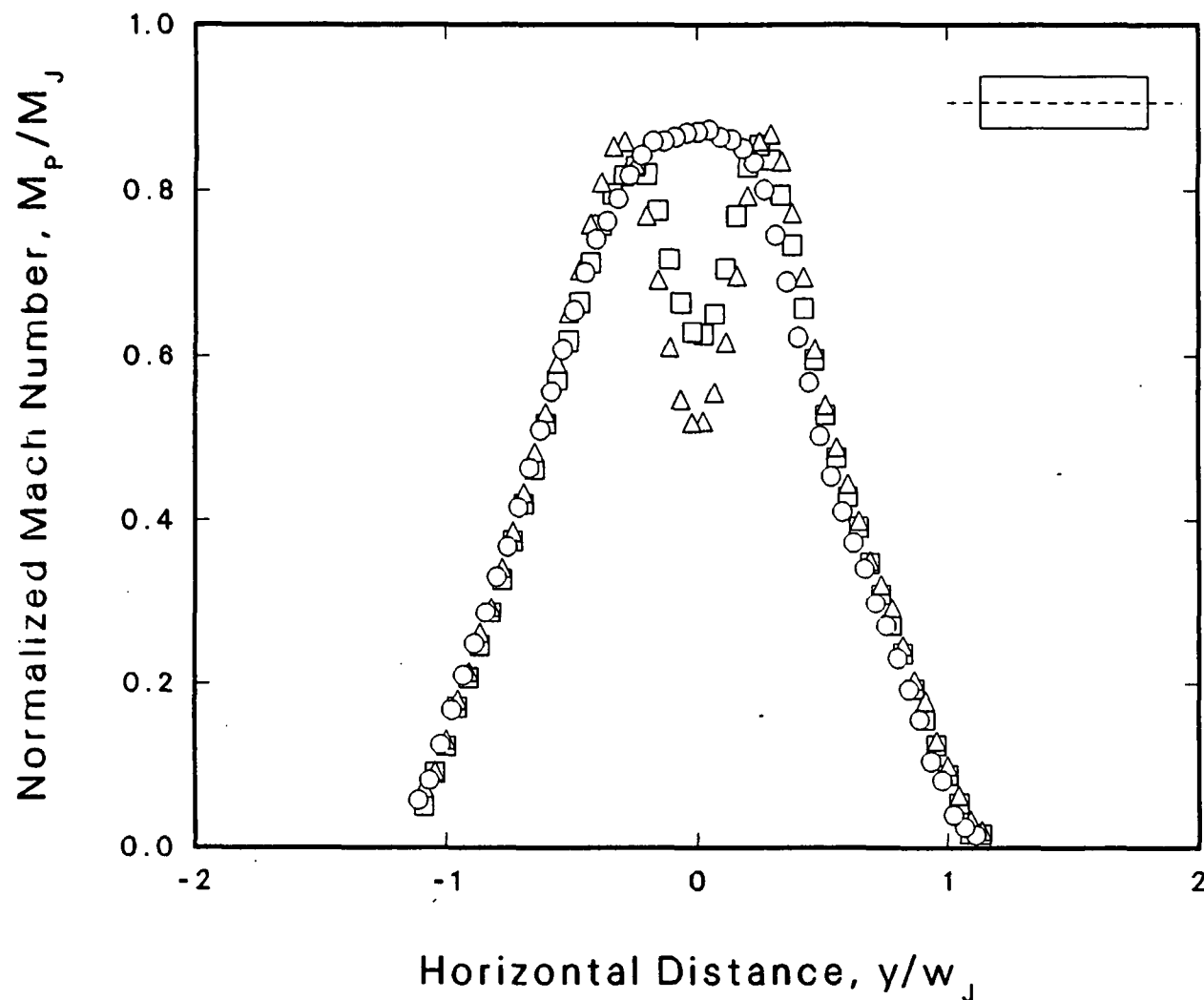
Sym	O	Δ
File	TAB350T	TAB351T
Config	0-0	I-B
M_j	0.802	0.803
T_{Tj}/T_A	2.29	2.30
T_{Tj}, K	641.6	648.5
U_j, mps	381.8	384.1
Re_{D_e}	0.398	0.394
Re_h	0.176	0.174
Re_w	0.706	0.697
p_A, kPa	98.544	98.544
T_A, K	280.5	281.6
De_j, mm	50.8	50.8
X/De_j	7.00	7.00
Z/h_j	-0.09	-0.09
$\Delta Y, mm$	-1.0	-2.0

Figure B.107 Mixing Modification, Horizontal Mach Number Profile, Config. I-B, $X/D_e=7$, $M_j=0.8$, $T_j/T_0=2.3$



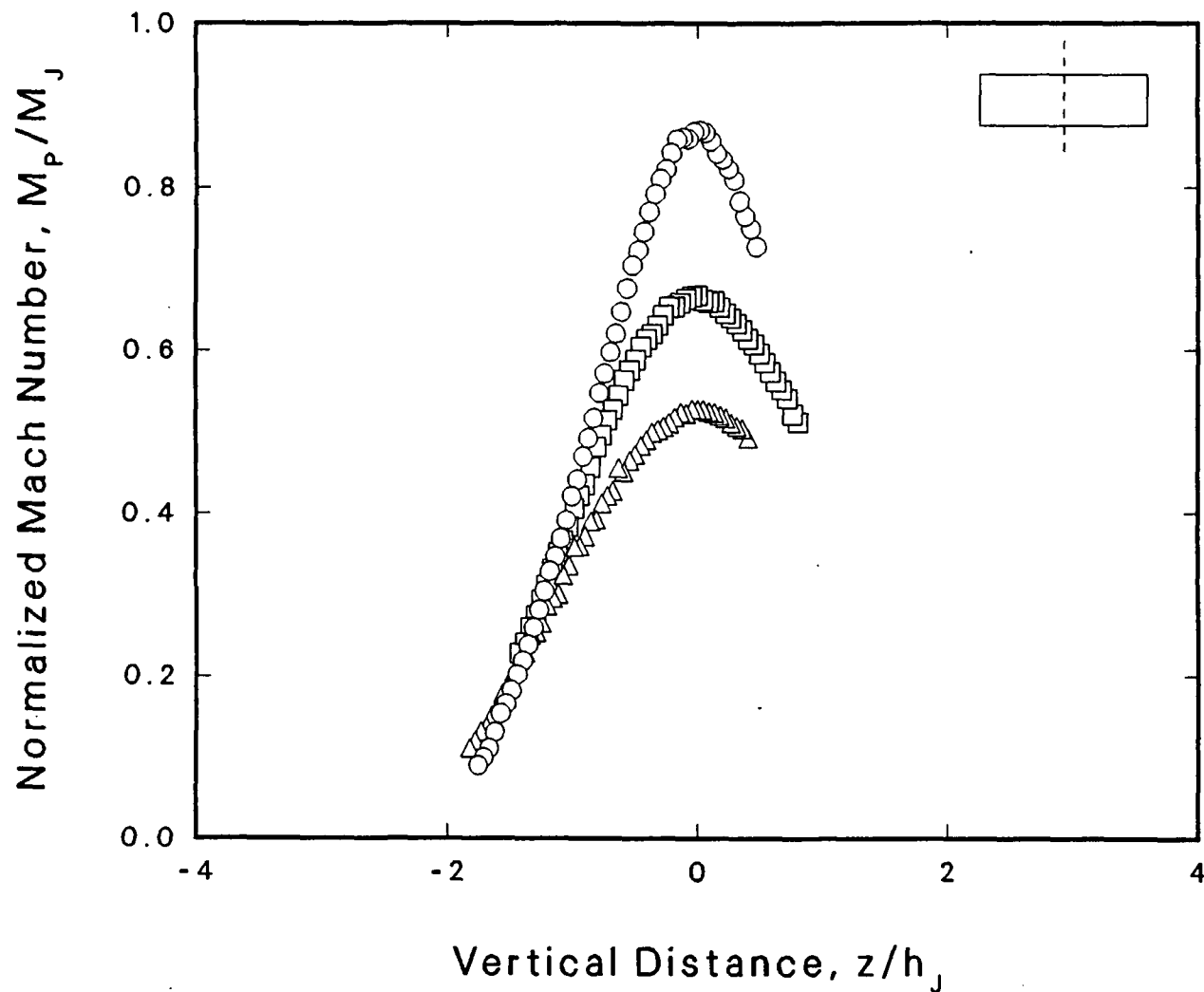
Sym	O	Δ
File	TAB349T	TAB352T
Config	0-0	I-B
M_j	0.803	0.803
T_{Tj}/T_A	2.30	2.30
T_{Tj} , K	643.4	647.0
U_j , mps	382.4	383.6
Re_{De}	0.397	0.394
Re_h	0.176	0.175
Re_w	0.703	0.698
p_A , kPa	98.578	98.442
T_A , K	279.4	281.7
De_j , mm	50.8	50.8
X/De_j	7.00	7.00
Y/w_j	0.00	0.00
ΔZ , mm	-2.0	-2.0

Figure B.108 Mixing Modification, Vertical Mach Number Profile,
Config. I-B, $X/De=7$, $M_j=0.8$, $T_j/T_0=2.3$



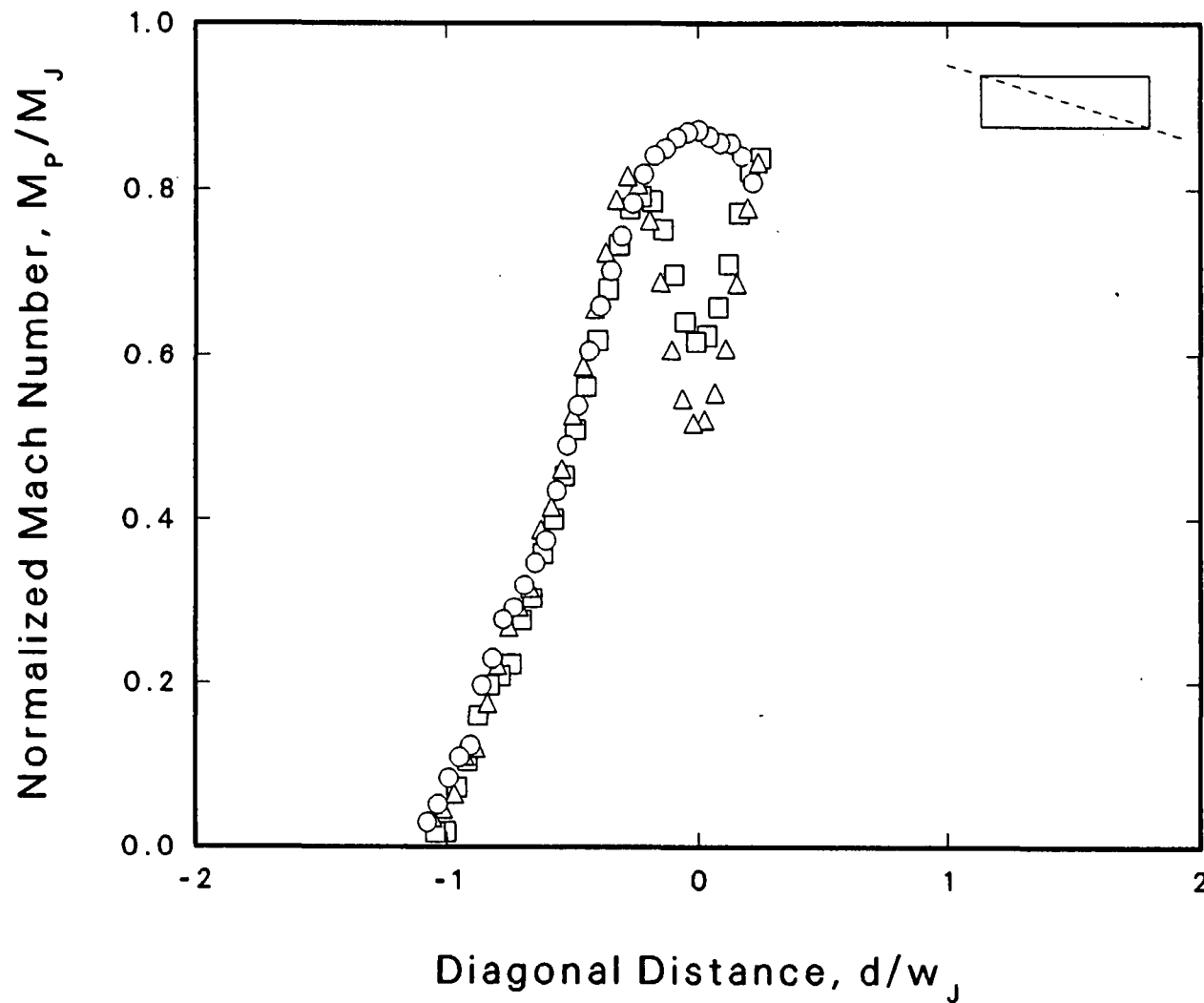
Sym	○	Δ	□
File	TAB337T	TAB340T	TAB341T
Config	0-0	I-B	III-B
M_j	0.802	0.800	0.801
T_{Tj}/T_A	2.28	2.26	2.27
T_{Tj} , K	632.6	618.2	628.2
U_j , mps	379.0	374.1	377.3
Re_{De}	0.406	0.416	0.409
Re_h	0.180	0.184	0.181
Re_w	0.718	0.737	0.724
p_A , kPa	98.781	98.815	98.815
T_A , K	277.6	274.0	276.5
De_j , mm	50.8	50.8	50.8
X/De_j	5.00	5.00	5.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	-2.0	-2.0

Figure B.109 Mixing Modification, Horizontal Mach Number Profile,
Config. I-B, $X/De=5$, $M_j=0.8$, $T_j/T_0=2.3$



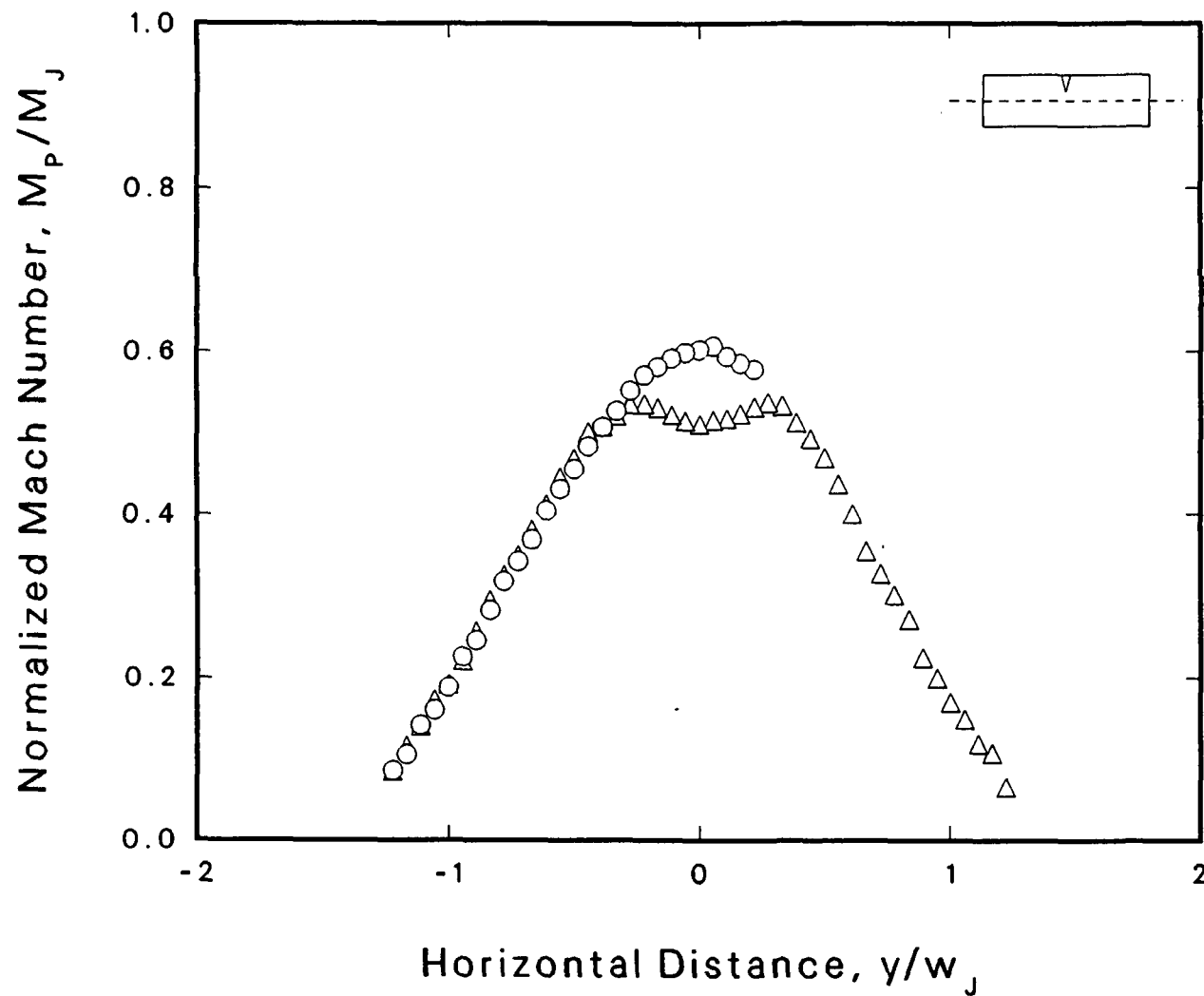
Sym	○	Δ	□
File	TAB338T	TAB339T	TAB342T
Config	0-0	I-B	III-B
M_j	0.803	0.801	0.801
T_{TJ}/T_A	2.27	2.29	2.25
T_{TJ} , K	632.2	620.9	627.7
U_j , mps	379.2	375.0	377.0
Re_{D_e}	0.407	0.414	0.409
Re_h	0.180	0.183	0.181
Re_w	0.720	0.733	0.724
p_A , kPa	98.781	98.781	98.849
T_A , K	277.9	271.4	278.4
De_j , mm	50.8	50.8	50.8
X/De_j	5.00	5.00	5.00
Y/w_j	0.00	0.00	0.00
ΔZ , mm	-0.5	1.0	-8.0

Figure B.110 Mixing Modification, Vertical Mach Number Profile,
Config. I-B, $X/D_e=5$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	○	△	□
File	TAB343T	TAB344T	TAB345T
Config	0-0	I-B	III-B
M_j	0.804	0.803	0.804
T_{Tj}/T_A	2.28	2.29	2.29
T_{Tj} , K	648.7	651.5	651.8
U_j , mps	384.4	385.0	385.4
Re_{De}	0.394	0.391	0.391
Re_h	0.174	0.173	0.173
Re_w	0.718	0.714	0.714
p_A , kPa	98.544	98.510	98.476
T_A , K	284.1	284.5	284.8
De_j , mm	50.8	50.8	50.8
X/De_j	5.00	5.00	5.00
Z/h_j	0.00	0.00	0.00
ΔY , mm	0.0	-2.0	-3.0

Figure B.111 Mixing Modification, Diagonal Mach Number Profile,
Config. I-B, $X/De=5$, $M_j=0.8$, $T_j/T_0=2.3$, $\theta=-14^\circ$



Sym	○	△
File	TAB332T	TAB336T
Config	0-0	III-B
M_j	0.801	0.802
T_{TJ}/T_A	2.29	2.28
T_{TJ}, K	624.8	629.1
U_j, mps	376.5	377.9
Re_{De}	0.408	0.409
Re_h	0.181	0.181
Re_w	0.723	0.723
p_A, kPa	97.968	98.849
T_A, K	272.6	275.4
De_j, mm	50.8	50.8
X/De_j	9.00	9.00
Z/h_j	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure B.112 Mixing Modification, Horizontal Mach Number Profile,
Config. III-B, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$

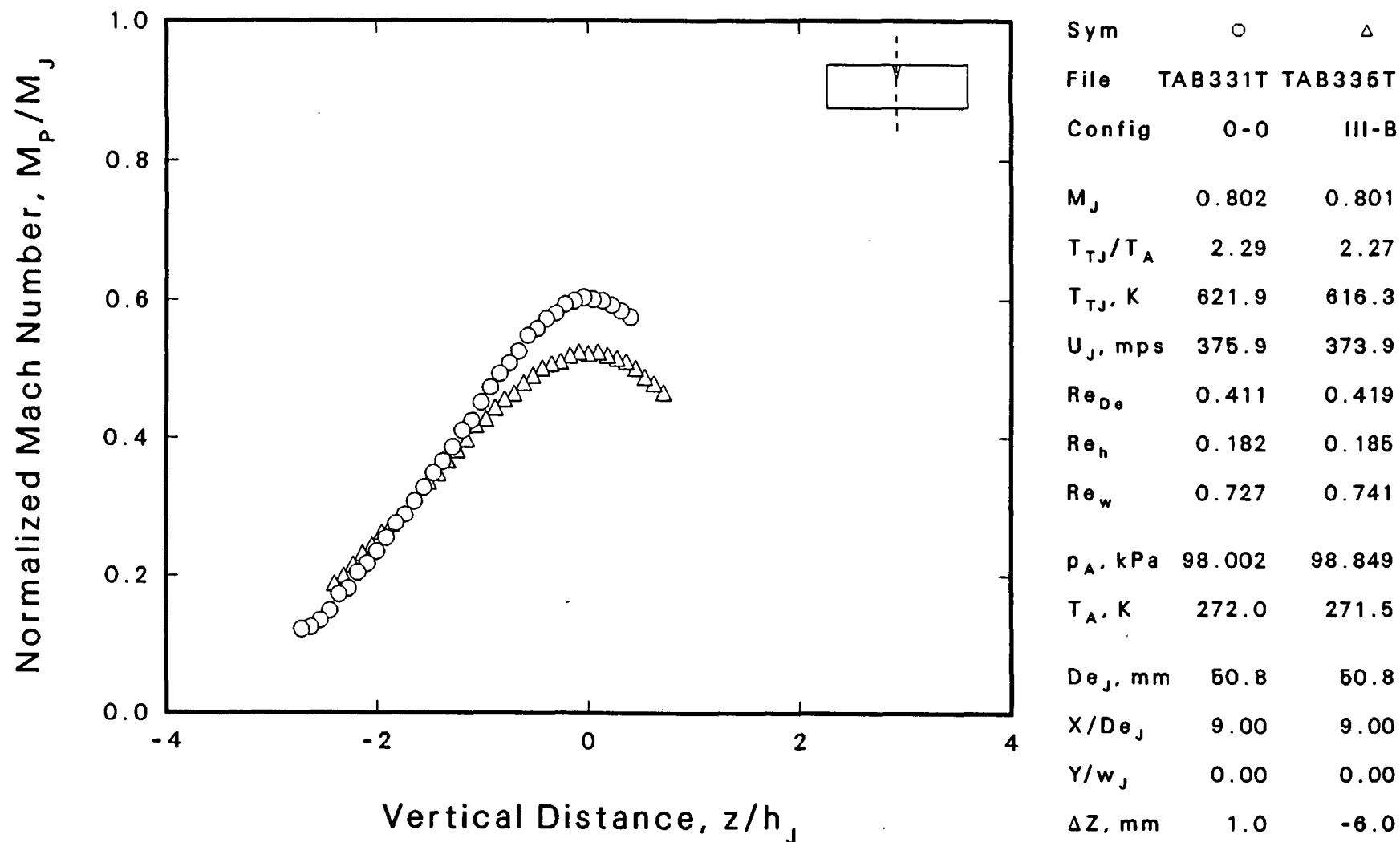


Figure B.113 Mixing Modification, Vertical Mach Number Profile,
Config. III-B, $X/De=9$, $M_j=0.8$, $T_j/T_0=2.3$

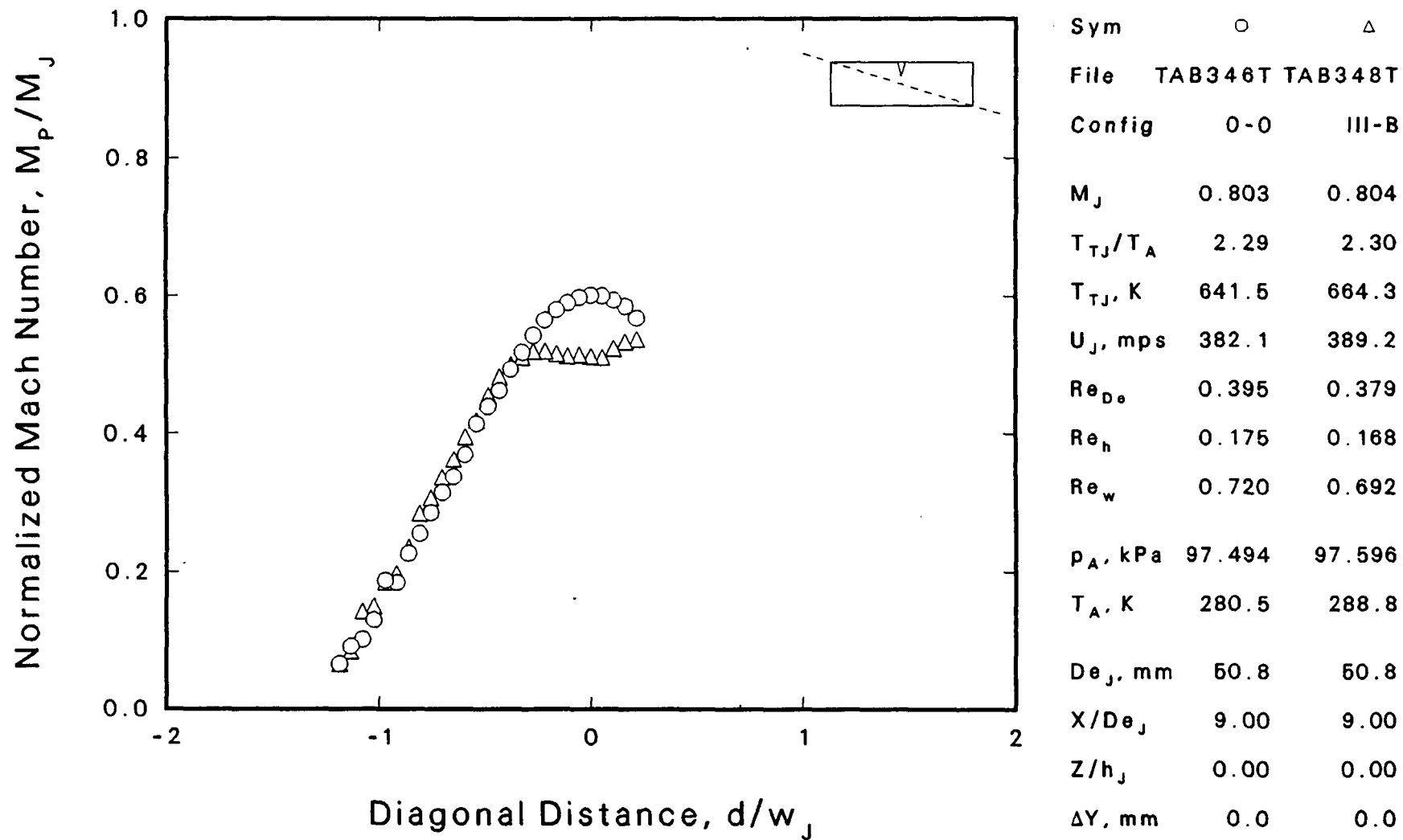
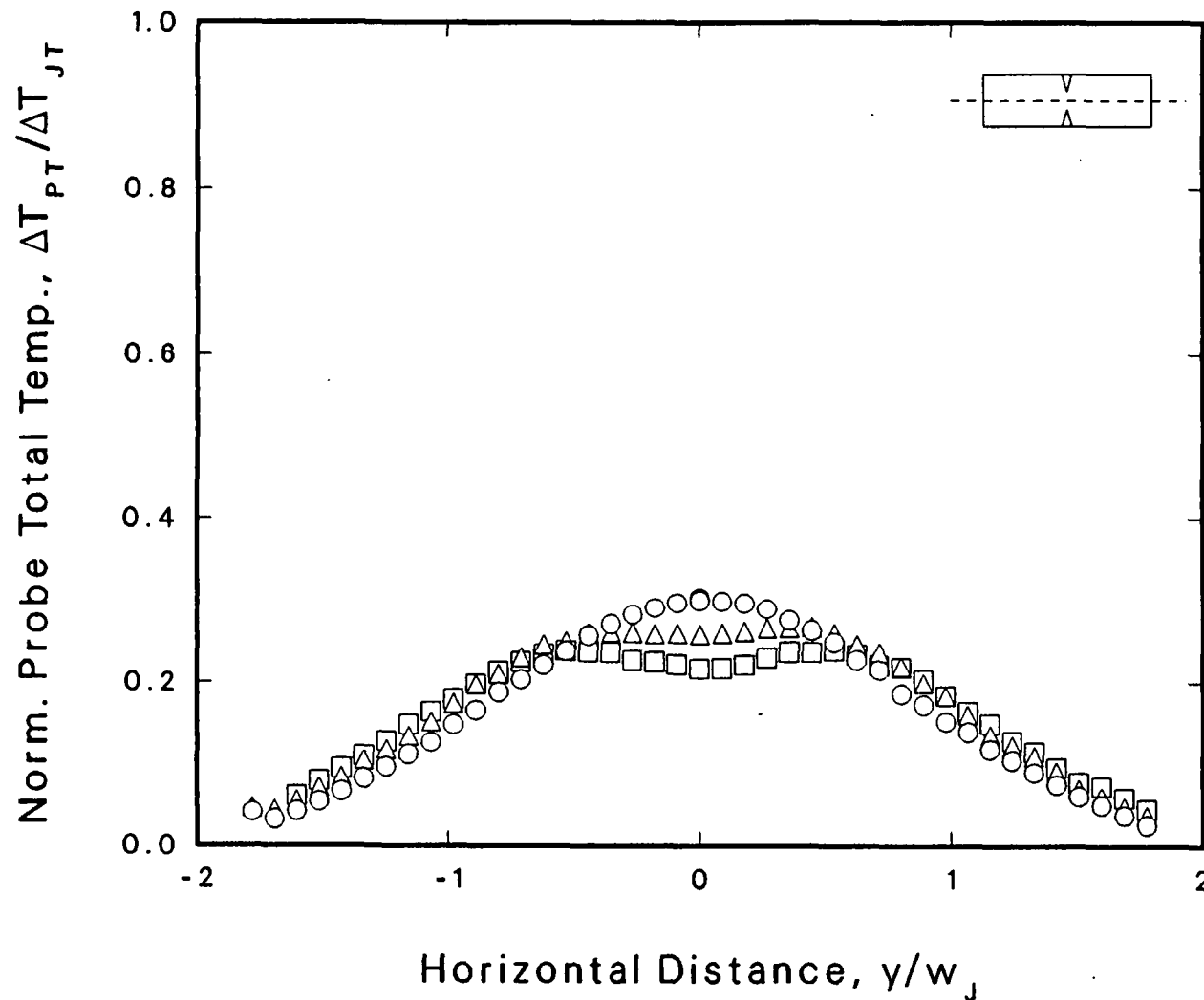
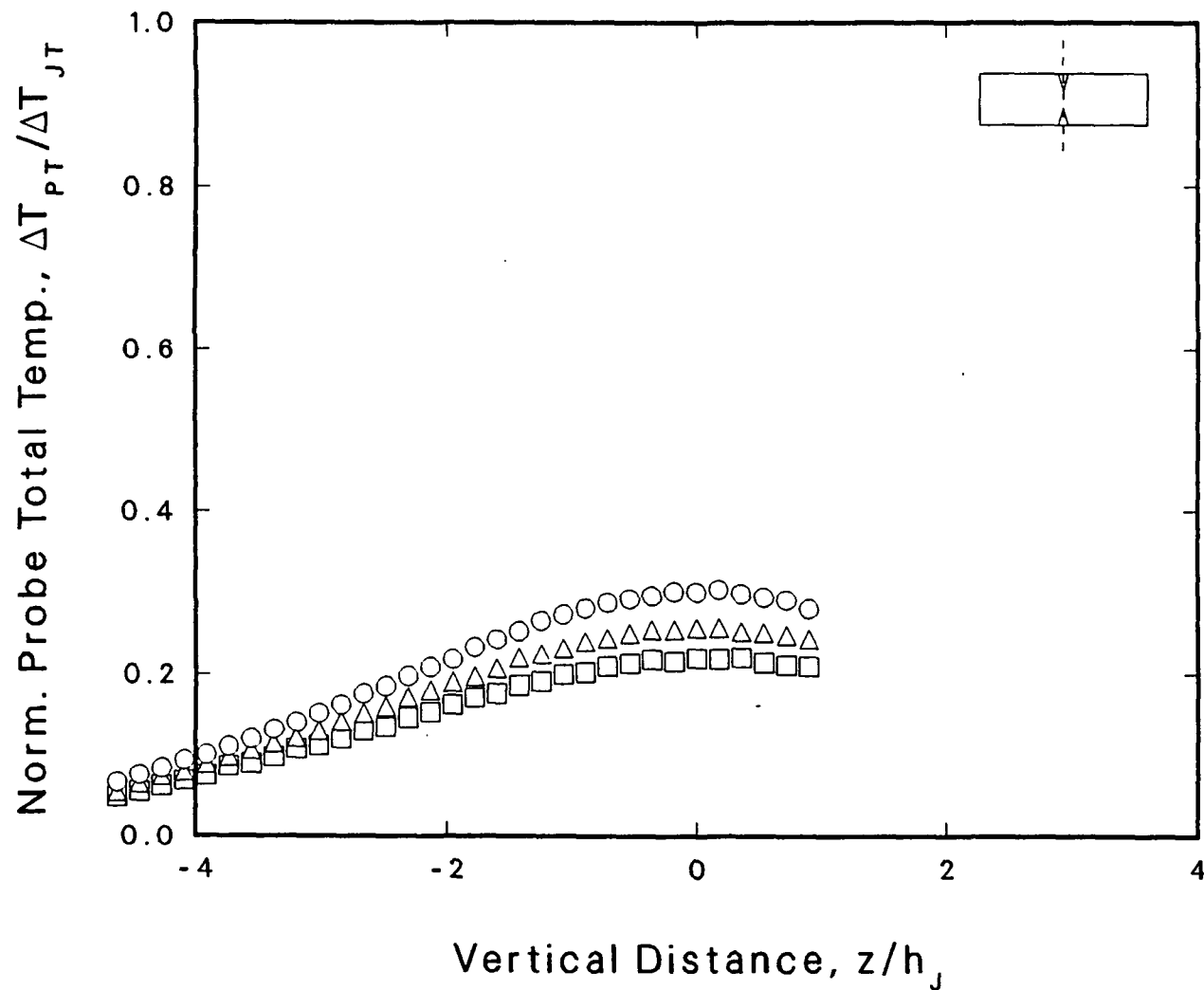


Figure B.114 Mixing Modification, Diagonal Mach Number Profile,
 Config. III-B, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$, $\theta=-14^\circ$



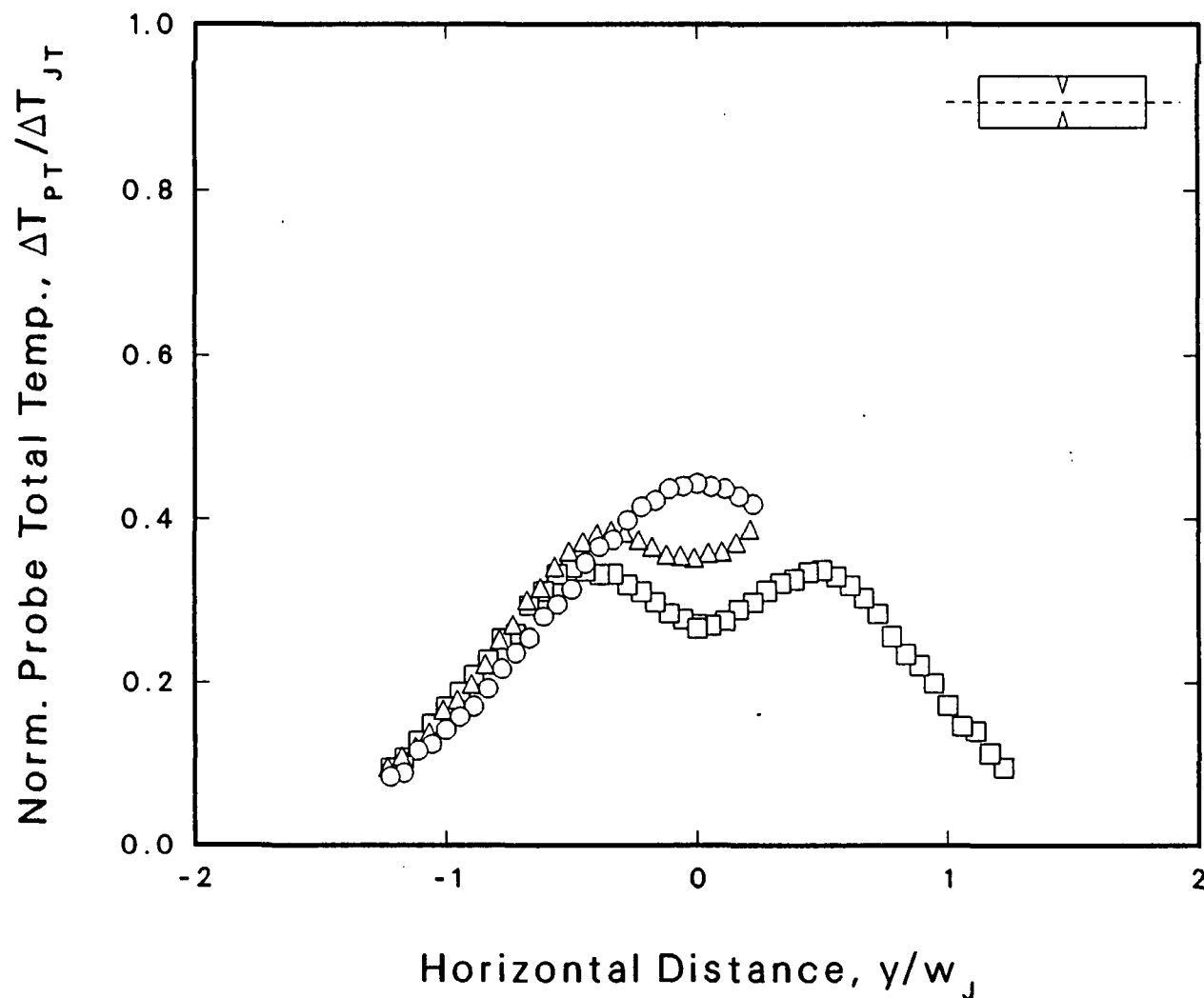
Sym	○	Δ	□
File	TAB356T	TAB354T	TAB357T
Config	0-0	I-B	I-C
M_J	0.804	0.805	0.803
T_{TJ}/T_A	2.29	2.29	2.31
T_{TJ}, K	652.4	652.9	654.9
U_J, mps	385.7	386.0	386.0
Re_{D_e}	0.388	0.388	0.385
Re_h	0.172	0.172	0.170
Re_w	0.688	0.688	0.681
p_A, kPa	97.765	97.799	97.528
T_A, K	284.4	285.1	283.7
De_J, mm	50.8	50.8	50.8
X/De_J	13.00	13.00	13.00
Z/h_J	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	0.0

Figure B.115 Mixing Modification, Horizontal Temperature Profile,
Config. I-B, I-C, $X/D_e=13$, $M_J=0.8$, $T_J/T_0=2.3$



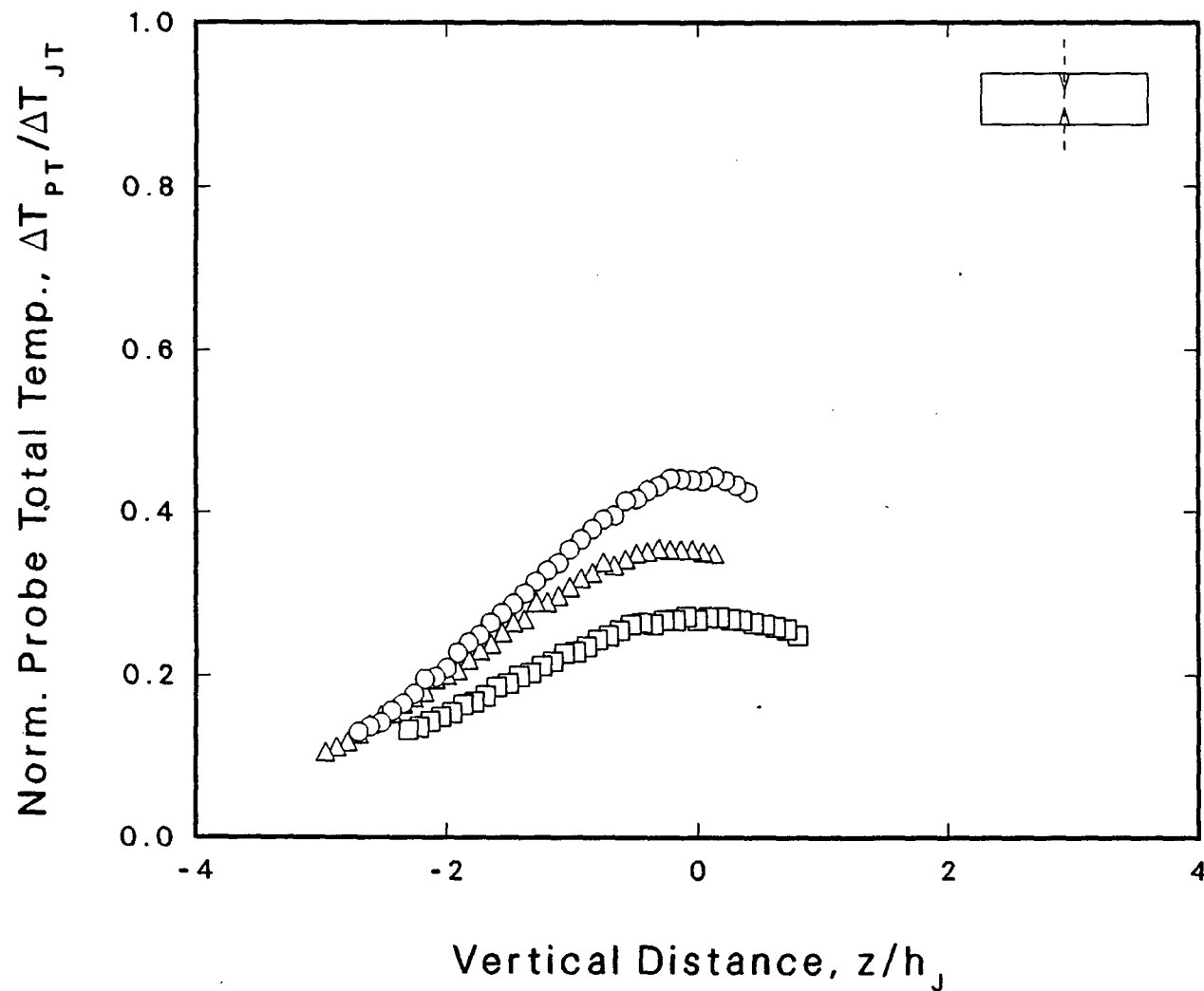
Sym	○	△	□
File	TAB355T	TAB353T	TAB358T
Config	0-0	I-B	I-C
M_J	0.804	0.803	0.803
T_{TJ}/T_A	2.29	2.31	2.30
T_{TJ}, K	651.5	659.7	652.9
U_J, mps	385.5	387.3	385.3
Re_{De}	0.389	0.384	0.386
Re_h	0.172	0.170	0.171
Re_w	0.689	0.680	0.683
p_A, kPa	97.765	98.205	97.460
T_A, K	284.8	285.3	284.3
De_J, mm	50.8	50.8	50.8
X/De_J	13.00	13.00	13.00
Y/w_J	0.00	0.00	0.00
$\Delta Z, mm$	0.0	0.0	0.0

Figure B.116 Mixing Modification, Vertical Temperature Profile,
Config. I-B, I-C, $X/De=13$, $M_j=0.8$, $T_j/T_0=2.3$



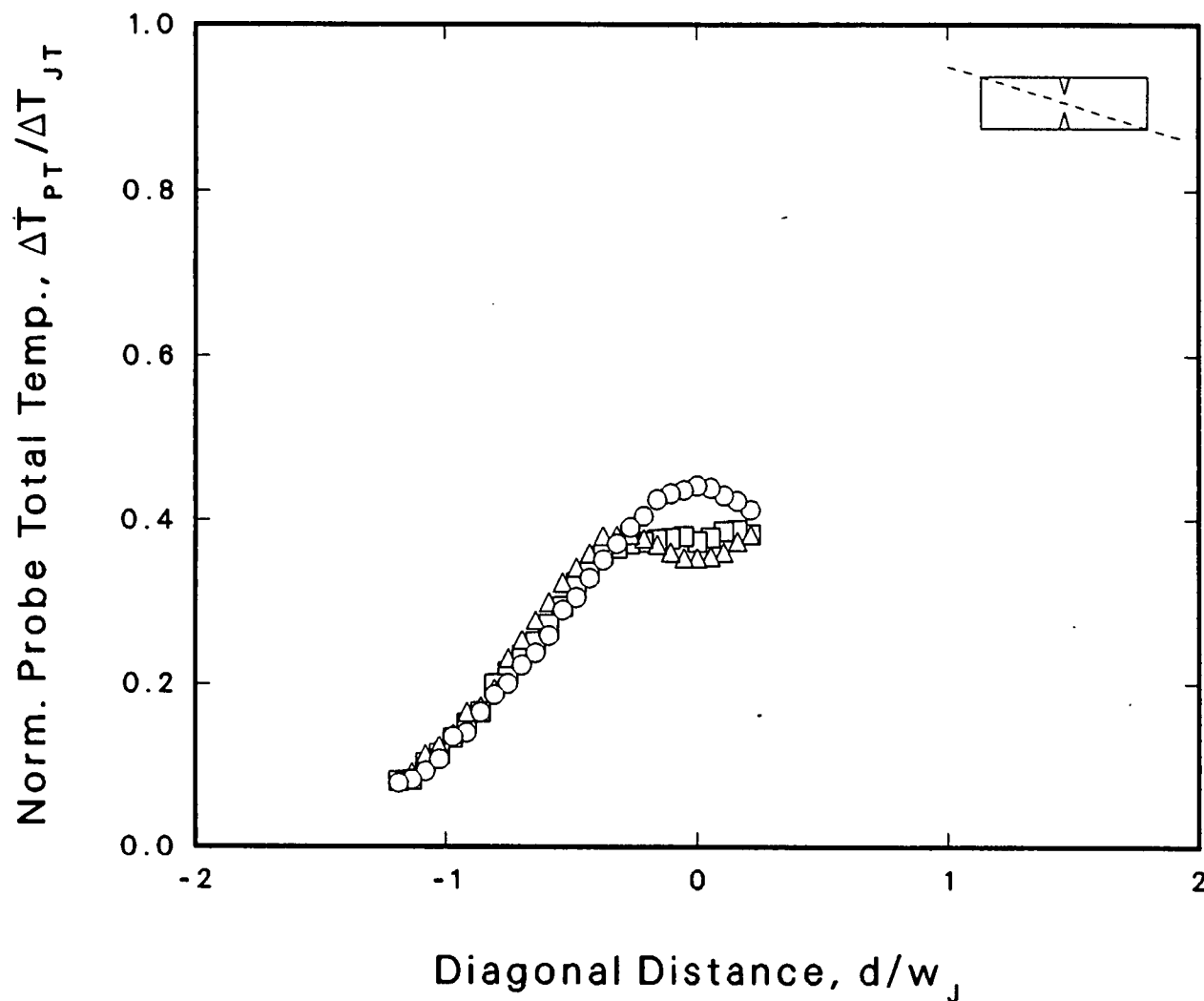
Sym	○	Δ	□
File	TAB332T	TAB333T	TAB359T
Config	0-0	I-B	I-C
M_J	0.801	0.802	0.804
T_{TJ}/T_A	2.29	2.29	2.30
T_{TJ}, K	624.8	613.9	652.1
U_J, mps	376.5	373.4	385.3
Re_{D_e}	0.408	0.421	0.386
Re_h	0.181	0.186	0.171
Re_w	0.723	0.745	0.683
p_A, kPa	97.968	98.815	97.189
T_A, K	272.6	268.6	283.4
De_J, mm	50.8	50.8	50.8
X/De_J	9.00	9.00	9.00
Z/h_J	0.00	0.00	0.00
$\Delta Y, mm$	0.0	1.0	0.0

Figure B.117 Mixing Modification, Horizontal Temperature Profile,
Config. I-B, I-C, $X/D_e=9$, $M_J=0.8$, $T_J/T_0=2.3$



Sym	○	△	□
File	TAB331T	TAB334T	TAB360T
Config	0-0	I-B	I-C
M_J	0.802	0.801	0.804
T_{TJ}/T_A	2.29	2.28	2.31
T_{TJ}, K	621.9	615.2	652.2
U_J, mps	375.9	373.4	385.4
Re_{D_0}	0.411	0.419	0.386
Re_h	0.182	0.186	0.171
Re_w	0.727	0.742	0.684
p_A, kPa	98.002	98.815	97.291
T_A, K	272.0	269.8	282.8
De_J, mm	50.8	50.8	50.8
X/De_J	9.00	9.00	9.00
Y/w_J	0.00	0.00	0.00
$\Delta Z, mm$	1.0	7.0	-8.0

Figure B.118 Mixing Modification, Vertical Temperature Profile,
Config. I-B, I-C, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	○	△	□
File	TAB346T	TAB347T	TAB348T
Config	0-0	I-B	I-C
M_j	0.803	0.805	0.804
T_{TJ}/T_A	2.29	2.29	2.30
T_{TJ}, K	641.5	661.2	664.3
U_j, mps	382.1	388.3	389.2
Re_{D_o}	0.395	0.382	0.379
Re_h	0.175	0.169	0.168
Re_w	0.720	0.696	0.692
p_A, kPa	97.494	97.596	97.596
T_A, K	280.5	288.3	288.8
De_j, mm	50.8	50.8	50.8
X/De_j	9.00	9.00	9.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	0.0	0.0

Figure B.119 Mixing Modification, Horizontal Temperature Profile,
Config. I-B,I-C, $X/D_e=9$, $M_j=0.8$, $T_j/T_0=2.3$, $\theta=-14^\circ$

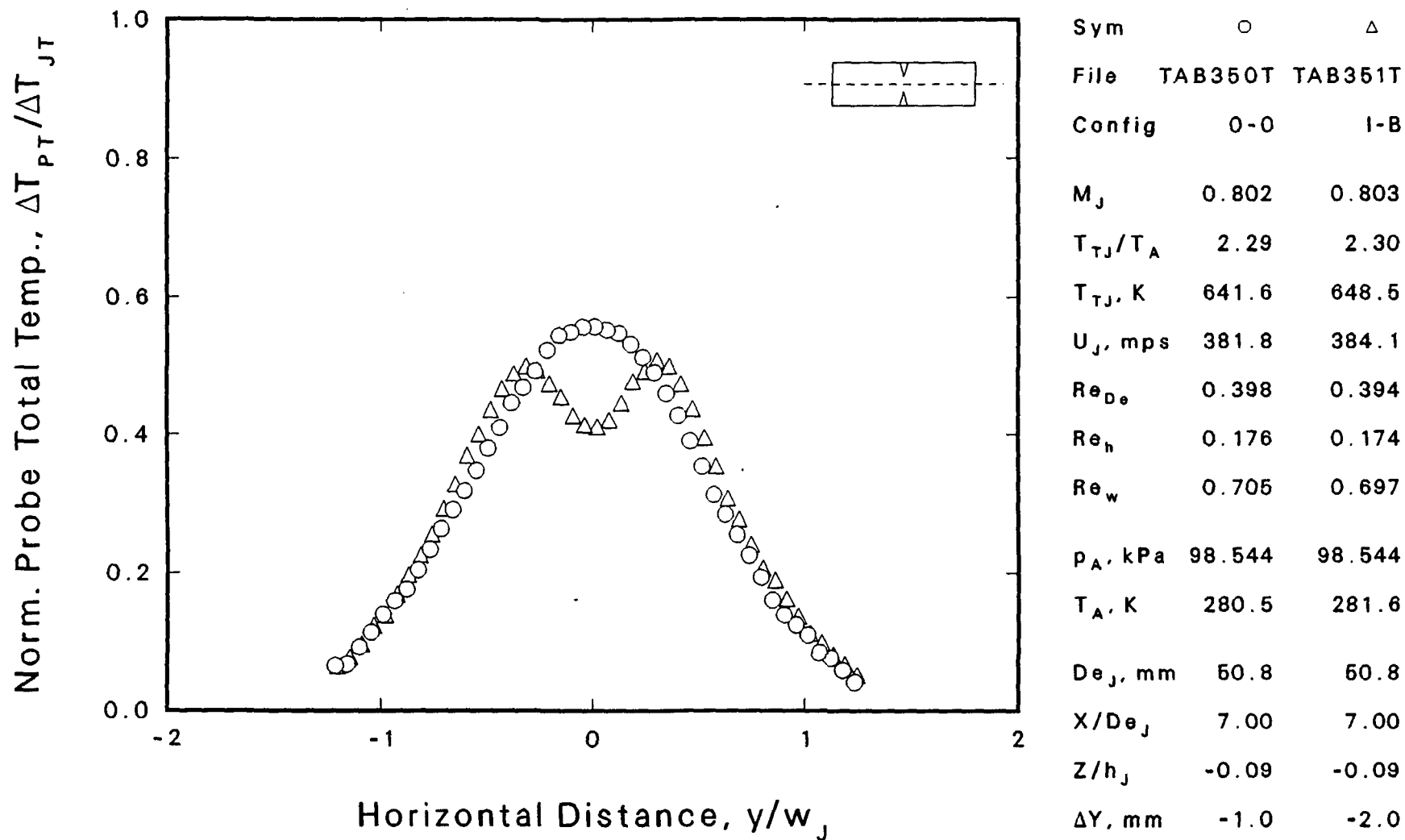
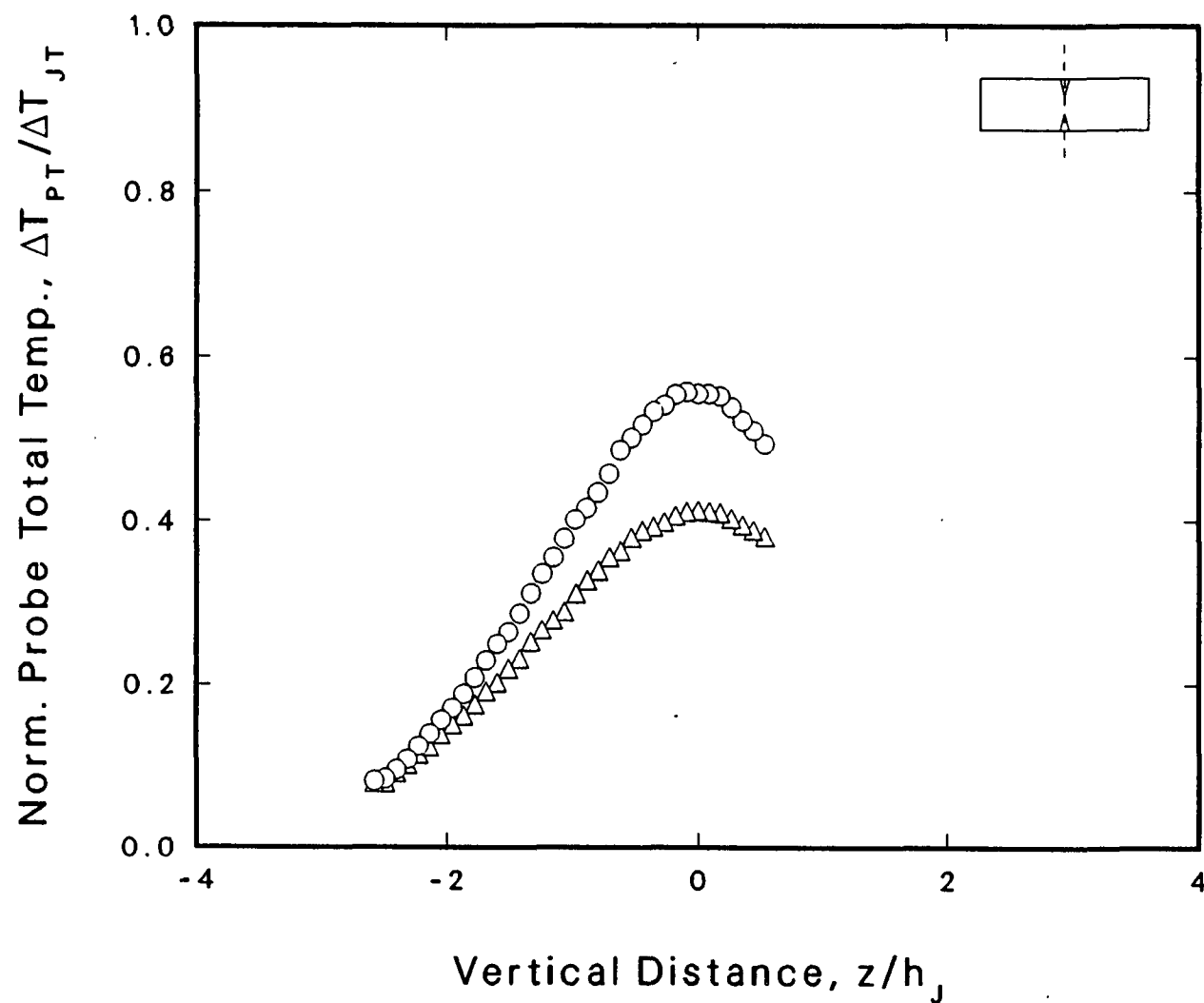
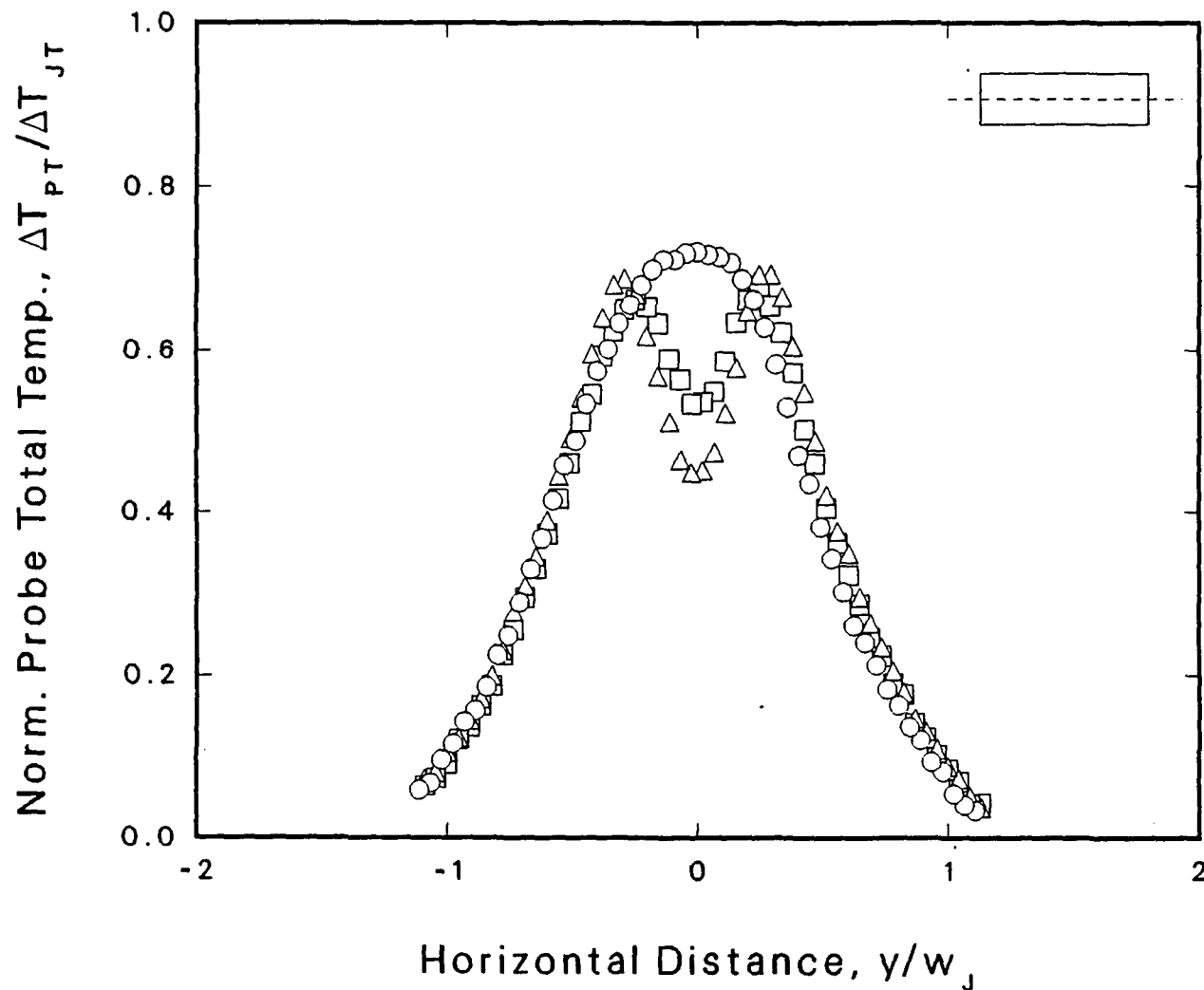


Figure B.120 Mixing Modification, Horizontal Temperature Profile,
Config. I-B, $X/De_J=7$, $M_J=0.8$, $T_j/T_0=2.3$



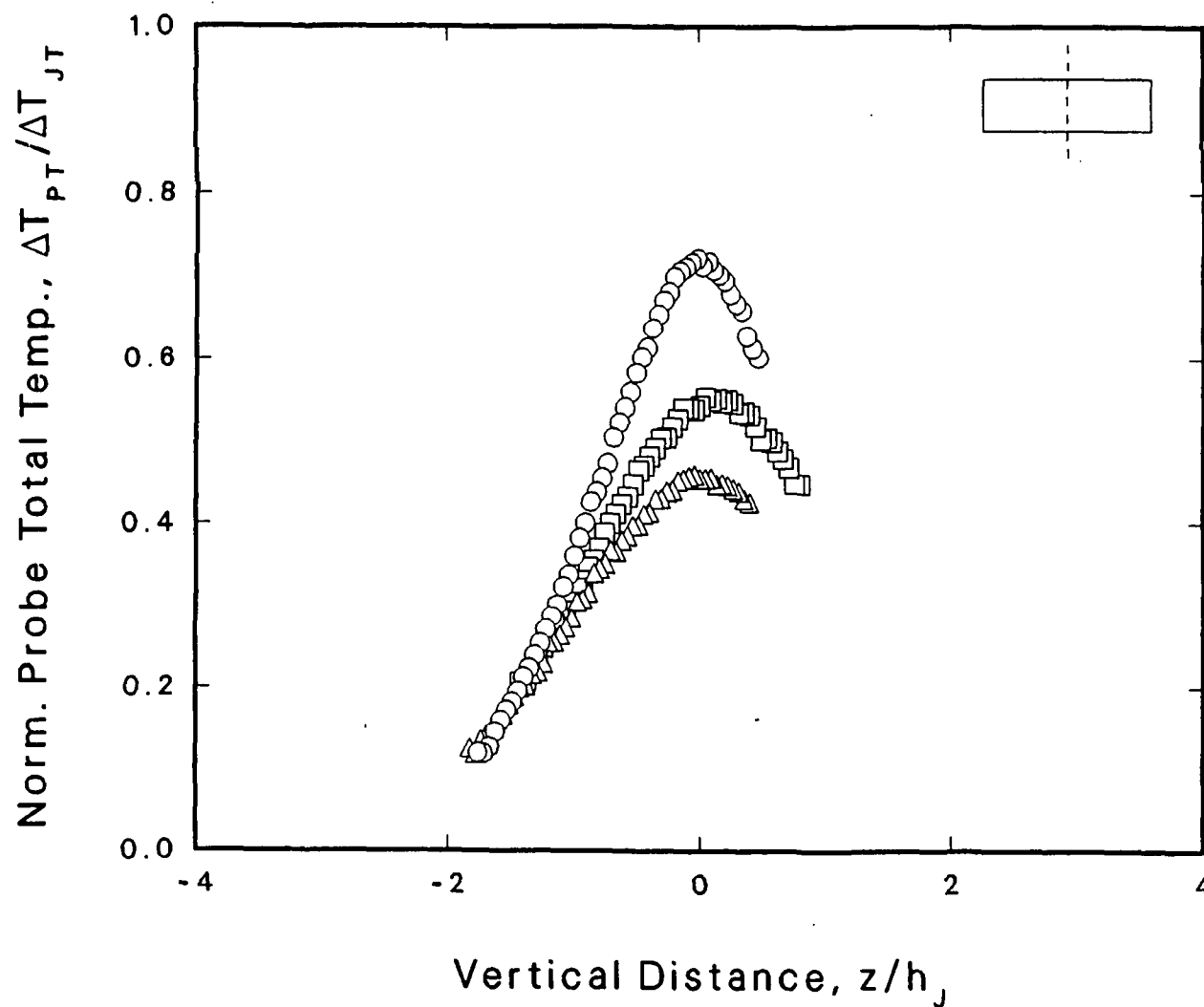
Sym	○	△
File	TAB349T	TAB352T
Config	0-0	I-B
M_j	0.803	0.803
T_{Tj}/T_A	2.30	2.30
T_{Tj} , K	643.4	647.0
U_j , mps	382.4	383.6
Re_{De}	0.397	0.394
Re_h	0.176	0.175
Re_w	0.703	0.698
p_A , kPa	98.578	98.442
T_A , K	279.4	281.7
De_j , mm	50.8	50.8
X/De_j	7.00	7.00
Y/w_j	0.00	0.00
ΔZ , mm	-2.0	-2.0

Figure B.121 Mixing Modification, Vertical Temperature Profile,
Config. I-B, $X/De=7$, $M_j=0.8$, $T_j/T_0=2.3$



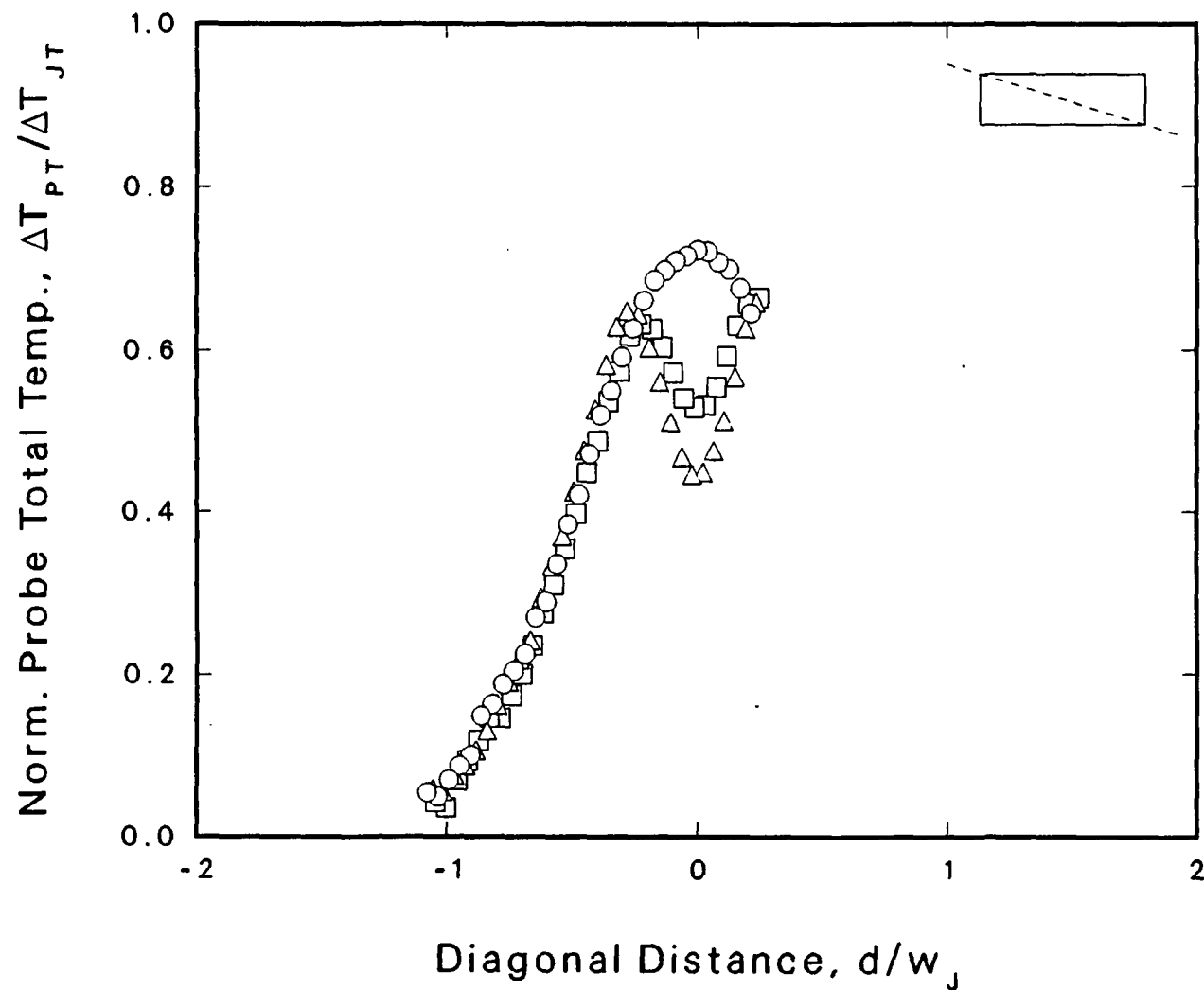
Sym	○	Δ	□
File	TAB337T	TAB340T	TAB341T
Config	0-0	I-B	III-B
M_j	0.802	0.800	0.801
T_{TJ}/T_A	2.28	2.26	2.27
T_{TJ}, K	632.6	618.2	628.2
U_j, mps	379.0	374.1	377.3
Re_{De}	0.406	0.416	0.409
Re_h	0.180	0.184	0.181
Re_w	0.718	0.737	0.724
p_A, kPa	98.781	98.815	98.815
T_A, K	277.6	274.0	276.5
De_j, mm	50.8	50.8	50.8
X/De_j	5.00	5.00	5.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	-2.0	-2.0

Figure B.122 Mixing Modification, Horizontal Temperature Profile,
Config. III-B, $X/De \approx 9$, $M_j = 0.8$, $T_j/T_0 = 2.3$



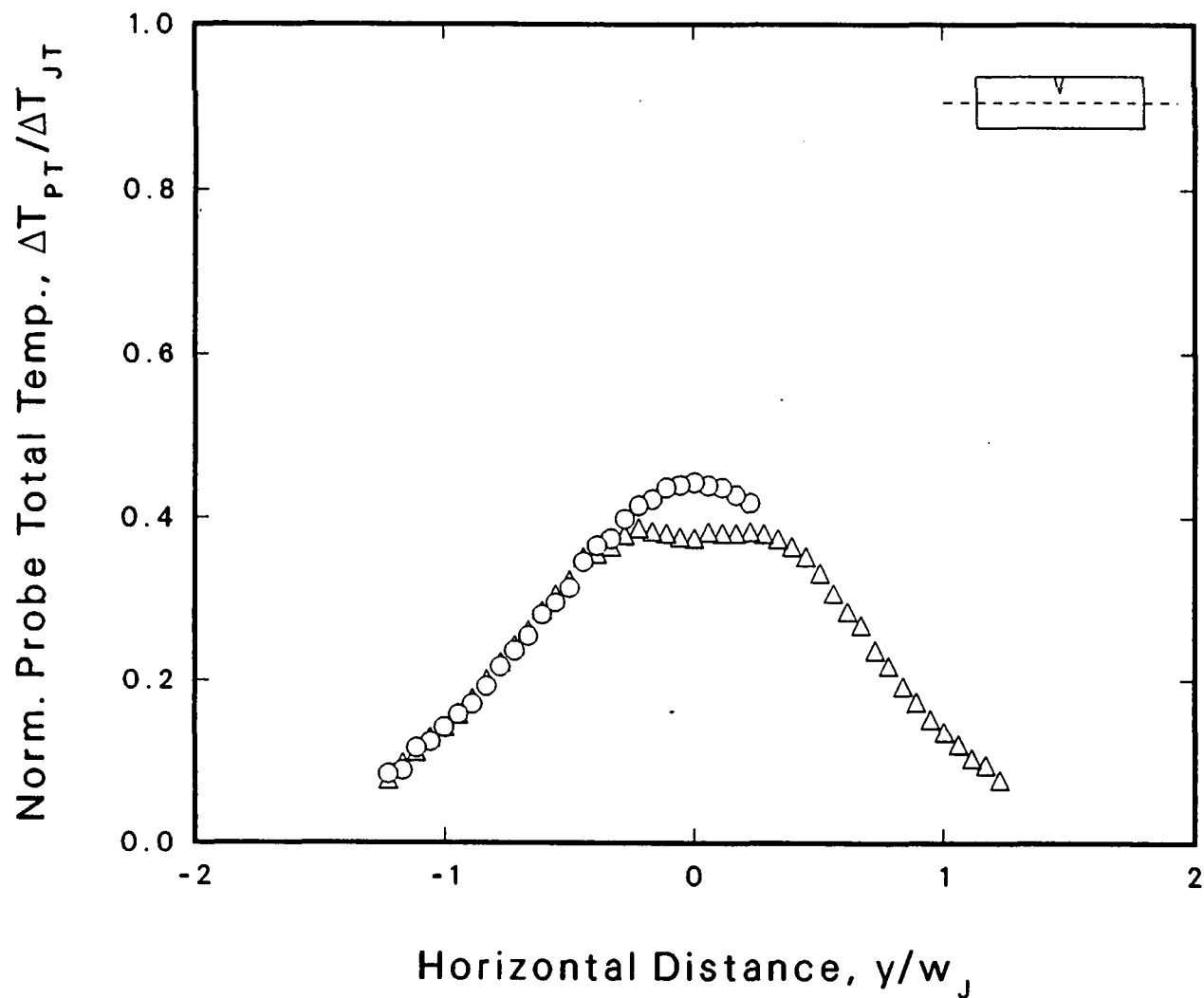
Sym	○	Δ	□
File	TAB338T	TAB339T	TAB342T
Config	0-0	I-B	III-B
M_J	0.803	0.801	0.801
T_{TJ}/T_A	2.27	2.29	2.25
T_{TJ}, K	632.2	620.9	627.7
U_J, mps	379.2	375.0	377.0
Re_{De}	0.407	0.414	0.409
Re_h	0.180	0.183	0.181
Re_w	0.720	0.733	0.724
p_A, kPa	98.781	98.781	98.849
T_A, K	277.9	271.4	278.4
De_J, mm	50.8	50.8	50.8
X/De_J	5.00	5.00	5.00
Y/w_J	0.00	0.00	0.00
$\Delta Z, mm$	-0.5	1.0	-8.0

Figure B.123 Mixing Modification, Vertical Temperature Profile,
Config. III-B, $X/De=9$, $M_j=0.8$, $T_j/T_0=2.3$



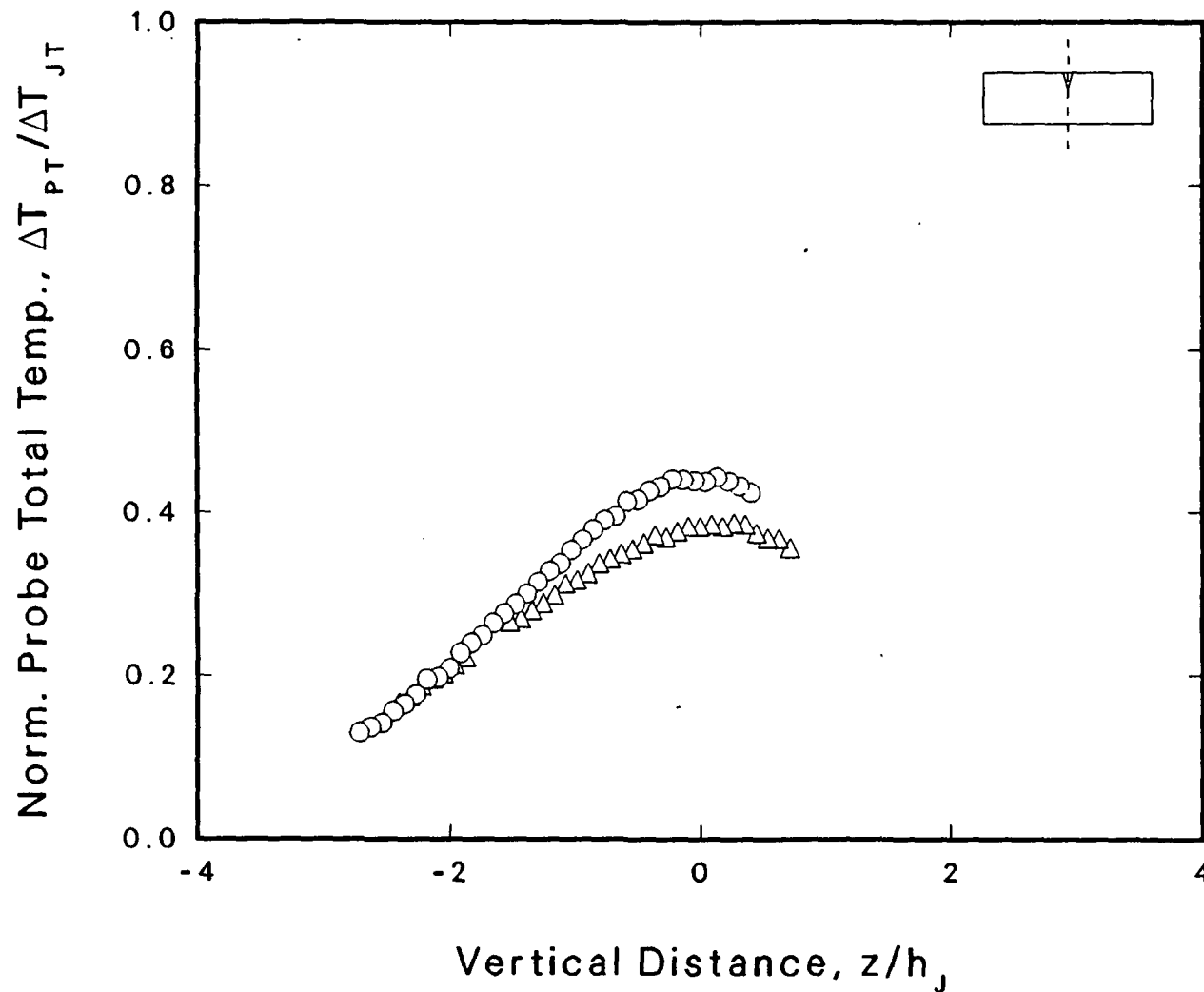
Sym	○	Δ	□
File	TAB343T	TAB344T	TAB345T
Config	0-0	I-B	III-B
M_j	0.804	0.803	0.804
T_{Tj}/T_A	2.28	2.29	2.29
T_{Tj}, K	648.7	651.5	651.8
U_j, mps	384.4	385.0	385.4
Re_{De}	0.394	0.391	0.391
Re_h	0.174	0.173	0.173
Re_w	0.718	0.714	0.714
p_A, kPa	98.544	98.510	98.476
T_A, K	284.1	284.5	284.8
De_j, mm	50.8	50.8	50.8
X/De_j	5.00	5.00	5.00
Z/h_j	0.00	0.00	0.00
$\Delta Y, mm$	0.0	-2.0	-3.0

Figure B.124 Mixing Modification, Diagonal Temperature Profile,
Config. III-B, $X/De=9$, $M_j=0.8$, $T_j/T_0=2.3$, $\theta=-14^\circ$



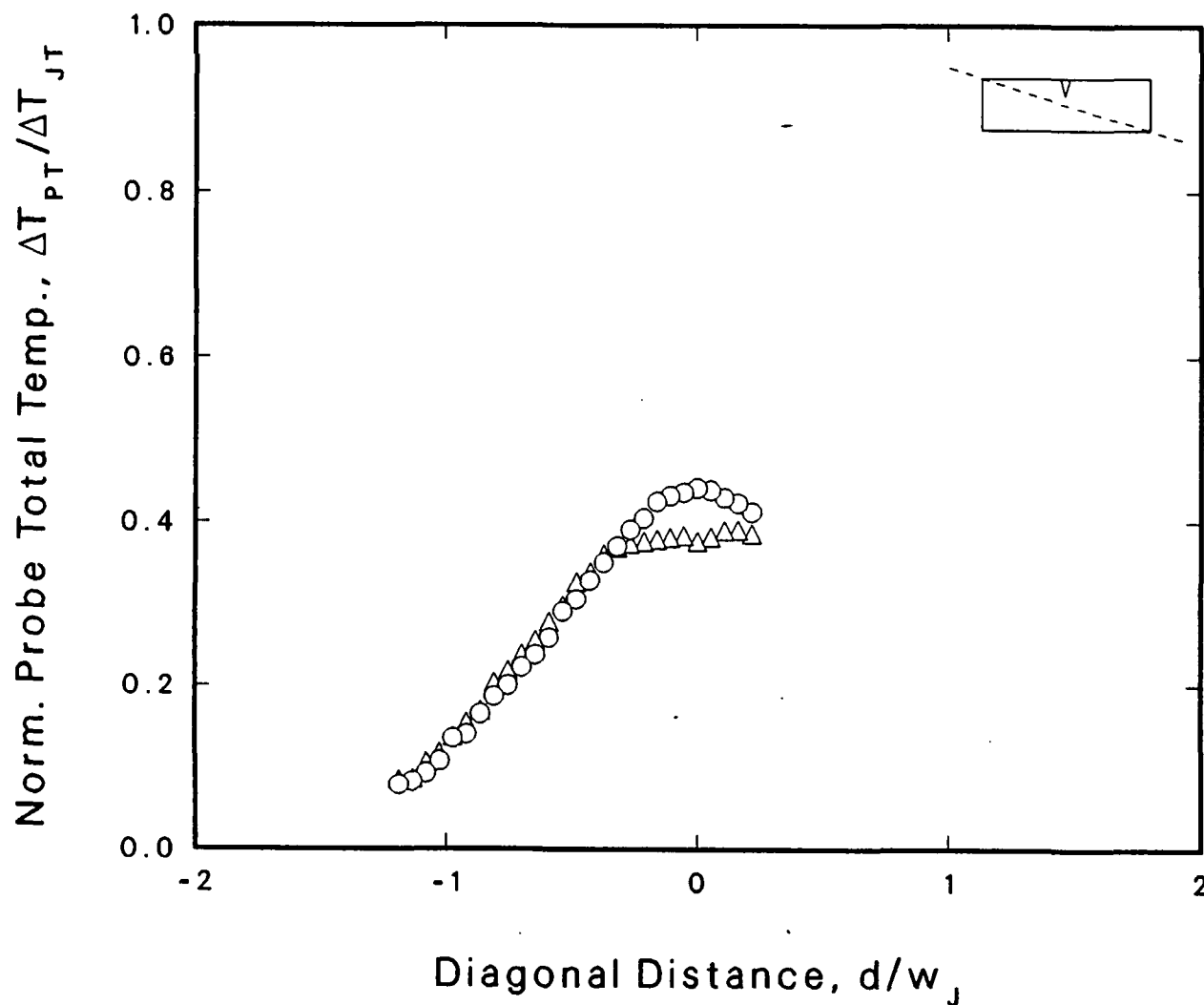
Sym	O	Δ
File	TAB332T	TAB336T
Config	0-0	III-B
M_J	0.801	0.802
T_{TJ}/T_A	2.29	2.28
T_{TJ}, K	624.8	629.1
U_J, mps	376.5	377.9
Re_{D_o}	0.408	0.409
Re_h	0.181	0.181
Re_w	0.723	0.723
p_A, kPa	97.968	98.849
T_A, K	272.6	275.4
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure B.125 Mixing Modification, Horizontal Temperature Profile,
Config. III-B, $X/D_e=9$, $M_J=0.8$, $T_j/T_0=2.3$



Sym	O	Δ
File	TAB331T	TAB335T
Config	0-0	III-B
M_j	0.802	0.801
T_{TJ}/T_A	2.29	2.27
T_{TJ} , K	621.9	616.3
U_j , mps	375.9	373.9
Re_{De}	0.411	0.419
Re_h	0.182	0.185
Re_w	0.727	0.741
p_A , kPa	98.002	98.849
T_A , K	272.0	271.5
De_j , mm	50.8	50.8
X/De_j	9.00	9.00
Y/w_j	0.00	0.00
ΔZ , mm	1.0	-6.0

Figure B.126 Mixing Modification, Vertical Temperature Profile,
Config. III-B, $X/De=9$, $M_j=0.8$, $T_j/T_0=2.3$



Sym	O	Δ
File	TAB346T	TAB348T
Config	0-0	III-B
M_J	0.803	0.804
T_{TJ}/T_A	2.29	2.30
T_{TJ}, K	641.5	664.3
U_J, mps	382.1	389.2
Re_{De}	0.395	0.379
Re_h	0.175	0.168
Re_w	0.720	0.692
p_A, kPa	97.494	97.596
T_A, K	280.5	288.8
De_J, mm	50.8	50.8
X/De_J	9.00	9.00
Z/h_J	0.00	0.00
$\Delta Y, mm$	0.0	0.0

Figure B.127 Mixing Modification, Diagonal Temperature Profile,
Config. III-B, $X/De=9$, $M_j=0.8$, $T_j/T_0=2.3$, $\theta=-14^\circ$

B-3.6 Miscellaneous

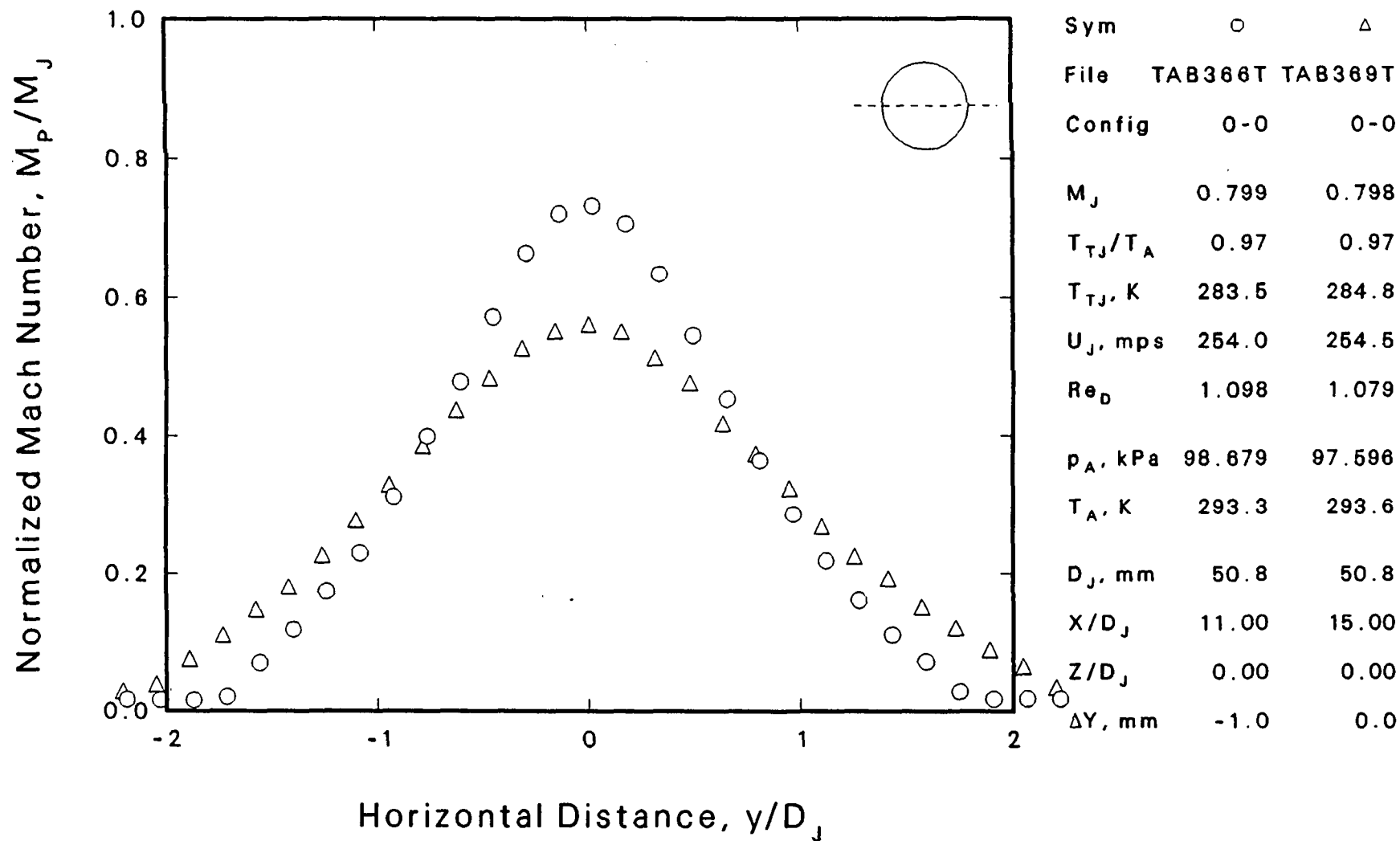


Figure B.128 Baseline Horizontal Mach Number Profiles, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1$, $X/D_e=11,15$, $D_e=50.8$ mm

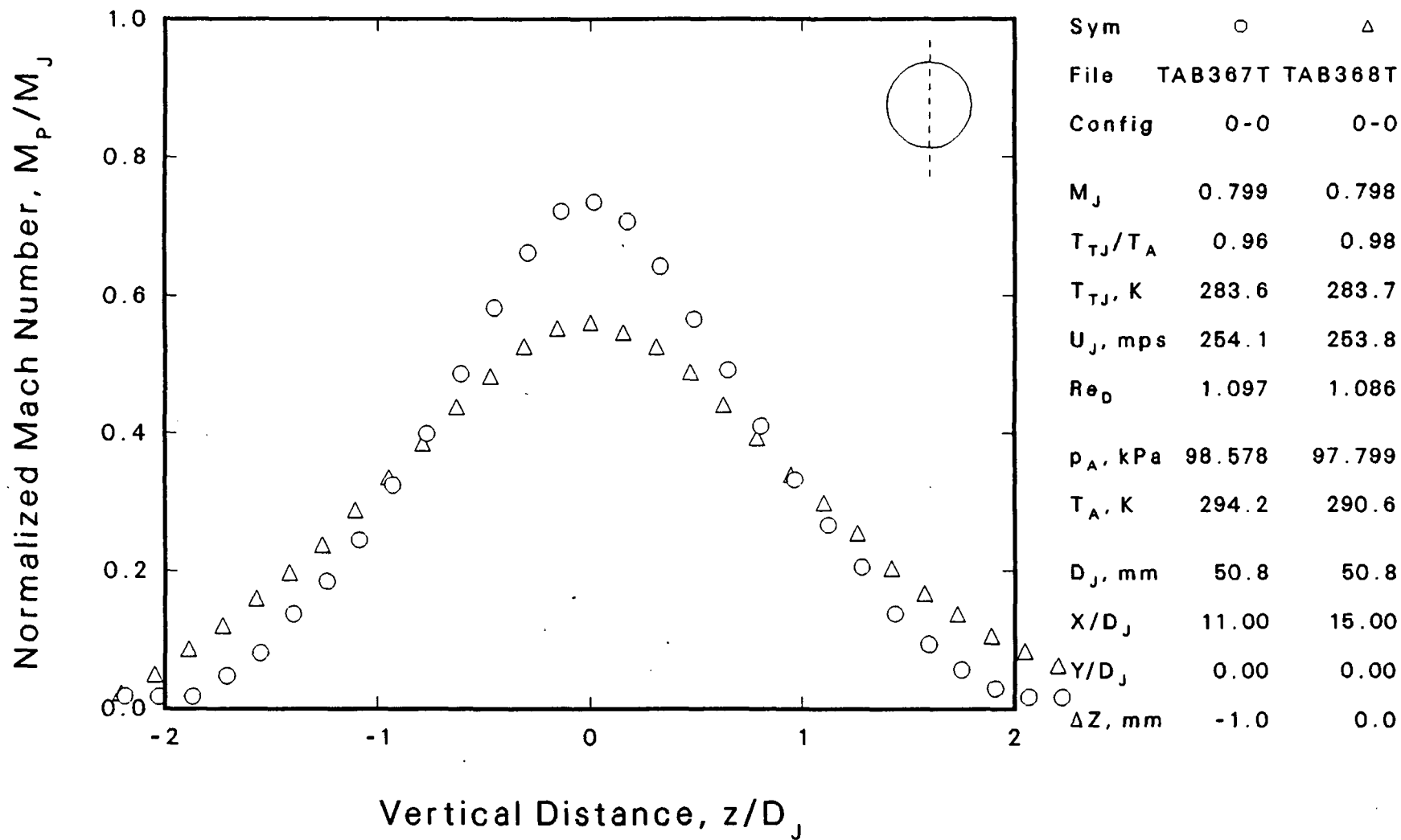


Figure B.129 Baseline Vertical Mach Number Profiles, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1$, $X/D_e=11,15$, $D_e=50.8$ mm

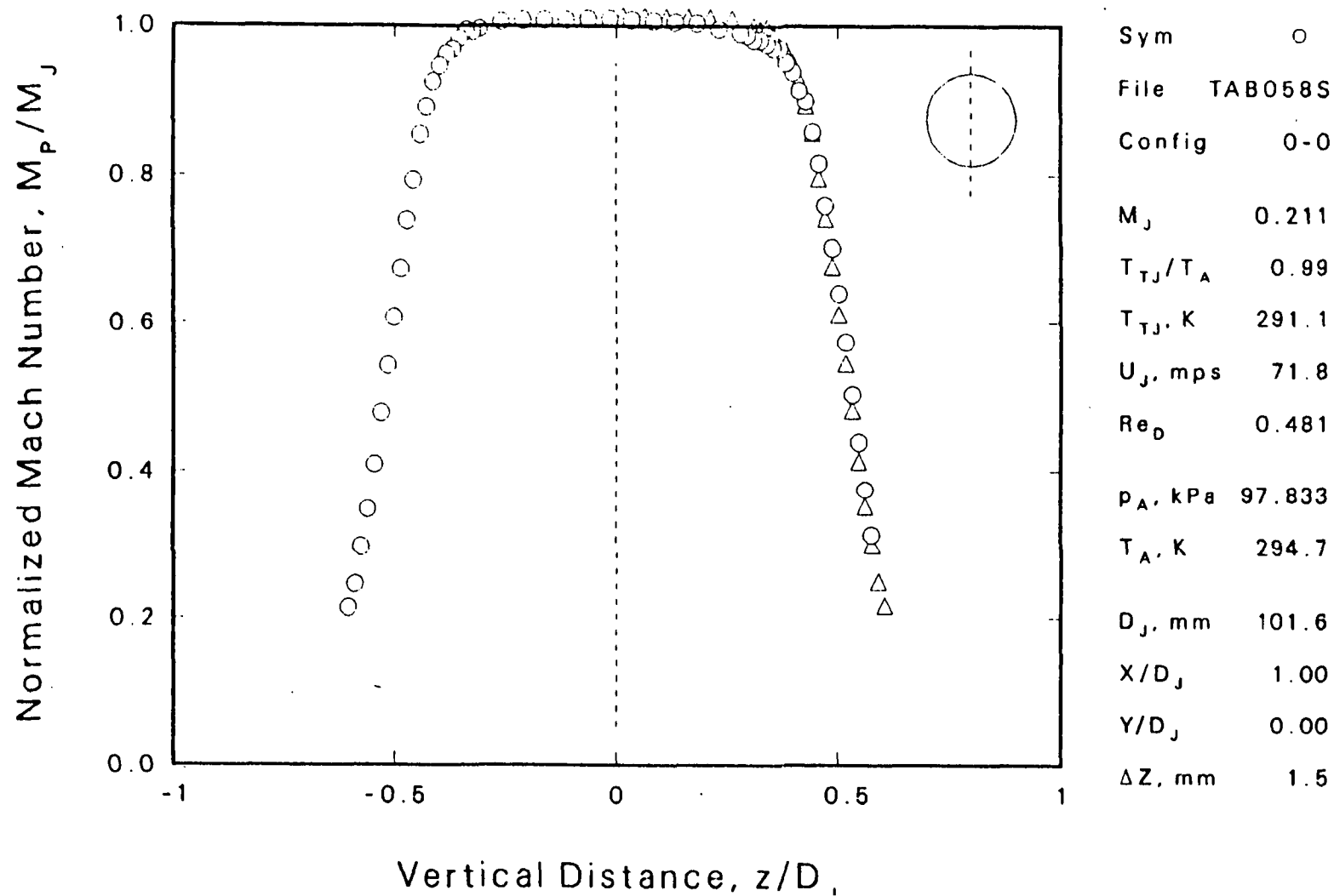


Figure B.130 Symmetry of Vertical Mach Number Profile, 4-Inch Pipe, $M_j=0.2$, $T_j/T_0=1$, $X/D=1$

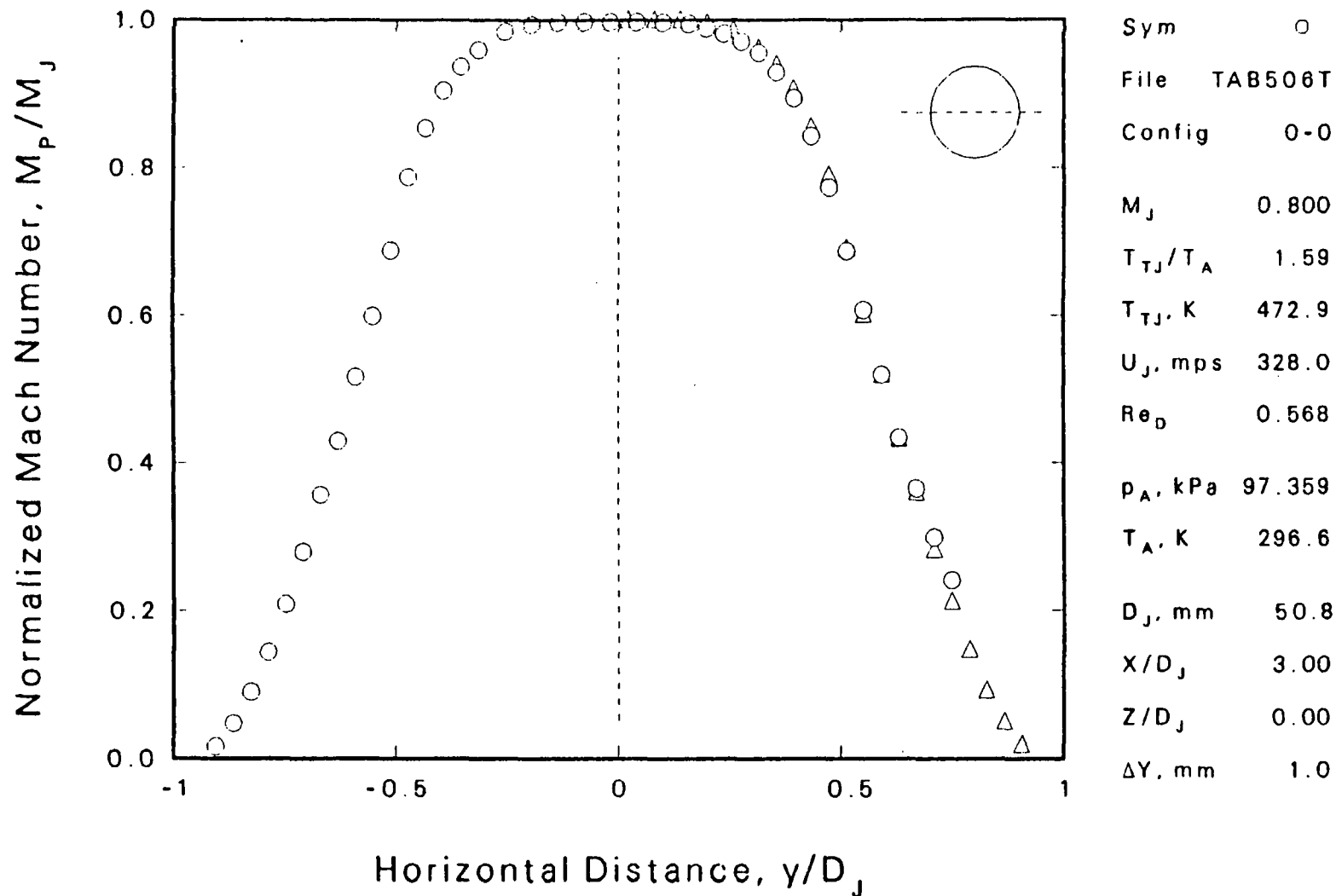


Figure B.131 Symmetry of Horizontal Mach Number Profile, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1.6$, $X/D=3$

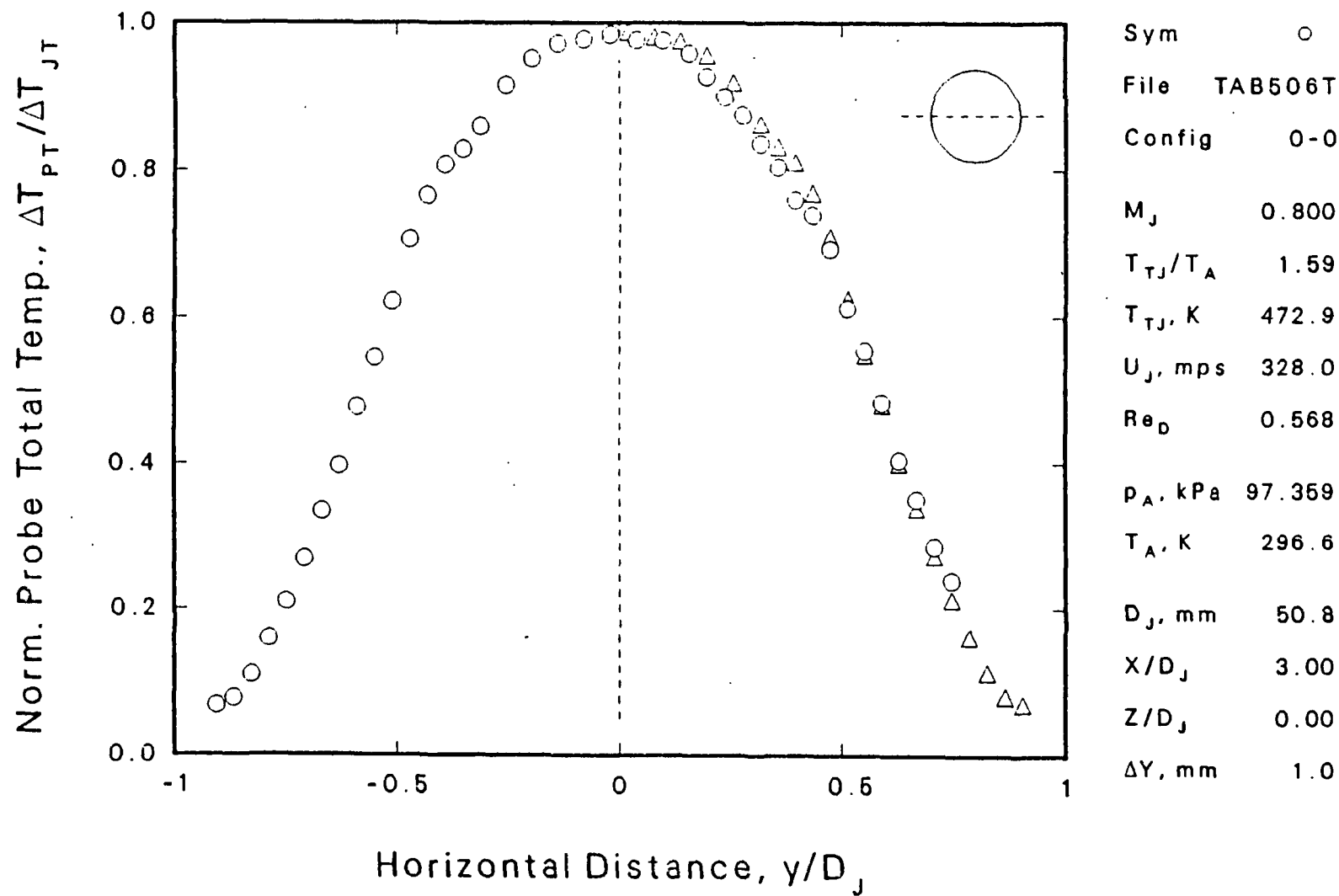


Figure B.132 Symmetry of Horizontal Temperature Profile, Circular Nozzle, $M_J=0.8$, $T_J/T_0=1.6$, $X/D=3$

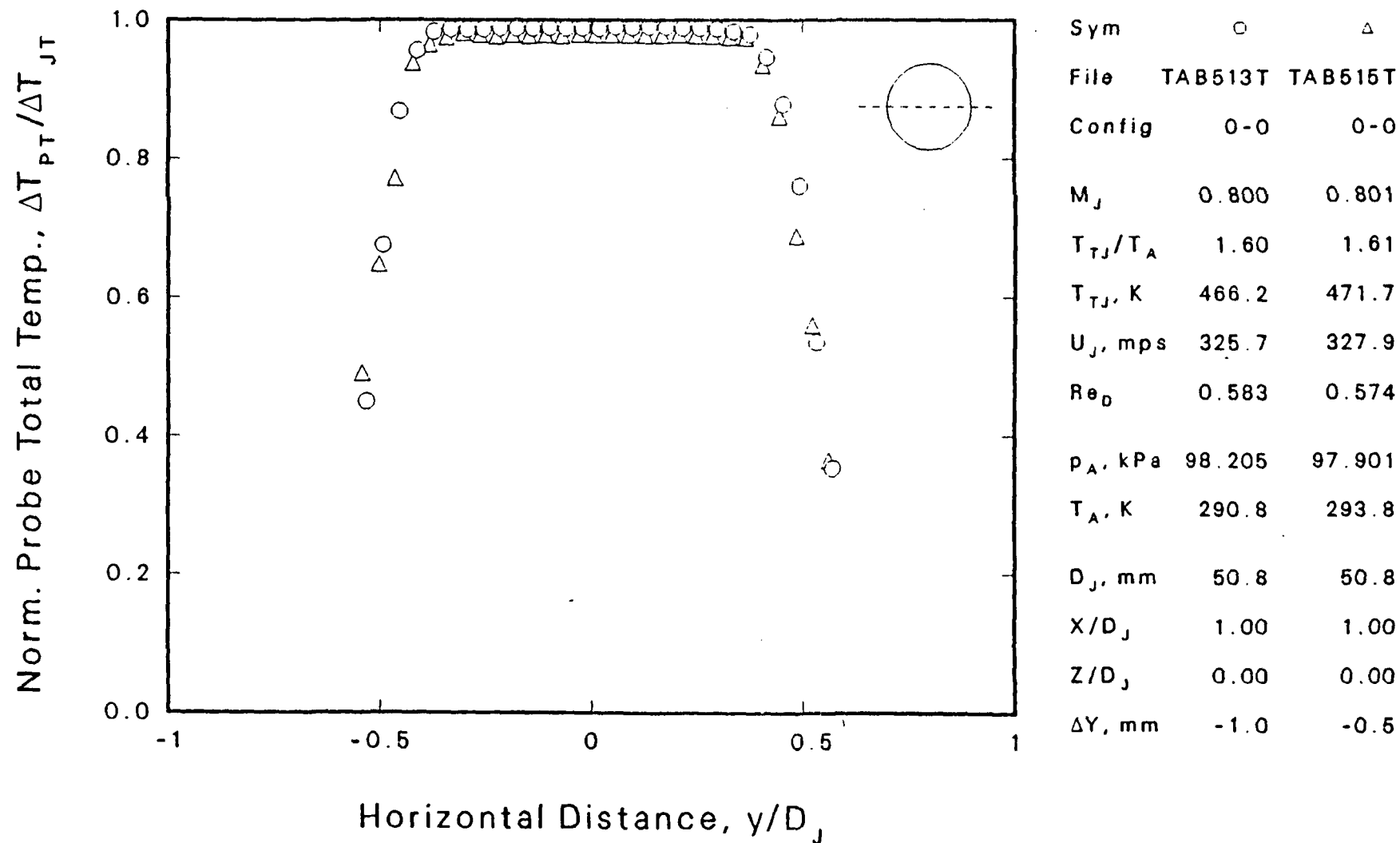
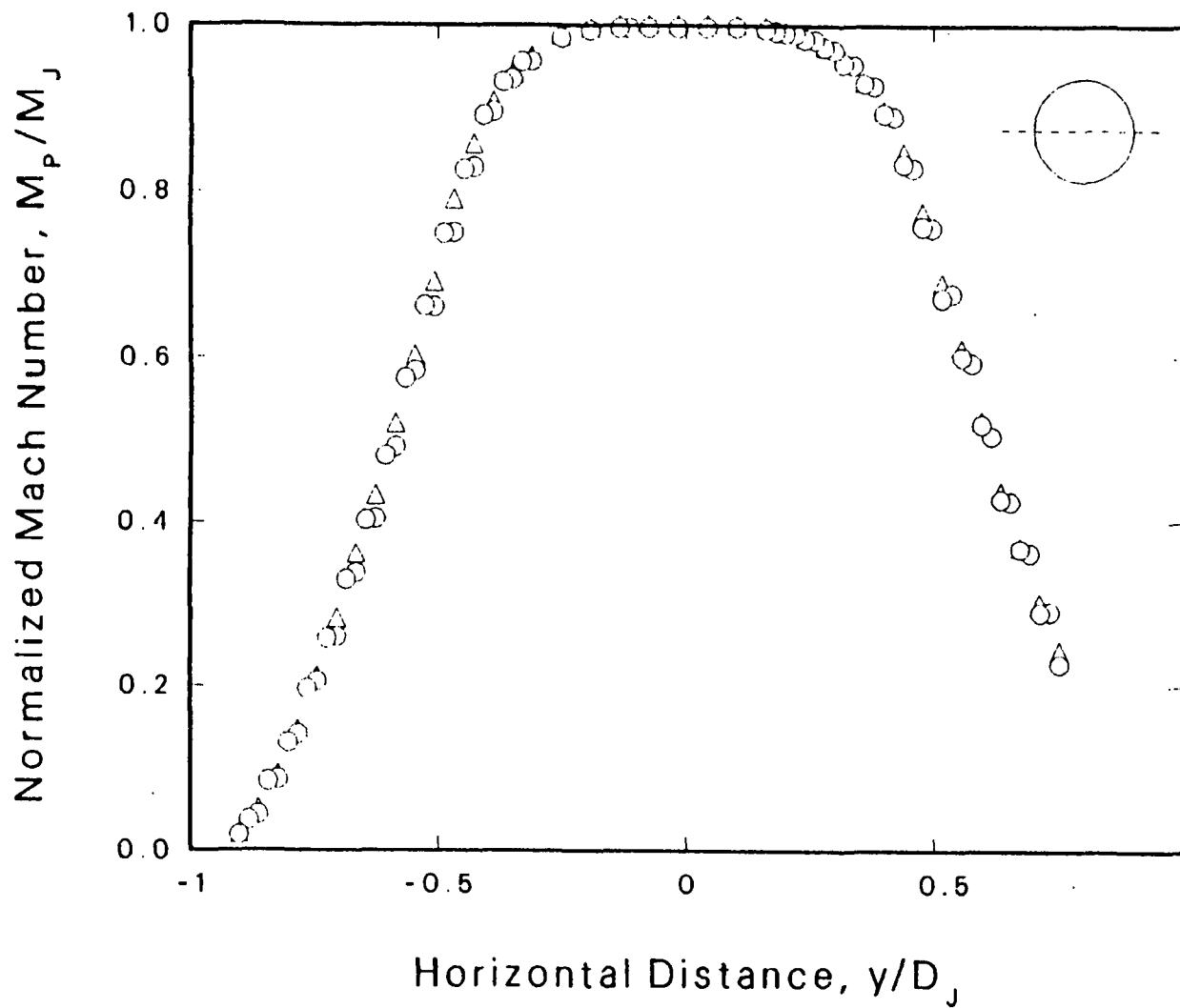


Figure B.133 Comparison of Temperature Profiles Measured by Centro and Kiel Probes, Circular Nozzle, $M_J=0.8$, $T_J/T_0=1.6$, $X/D=3$



Sym	○	△
File	TAB504S	TAB506S
Config	0-0	0-0
M_j	0.800	0.800
T_{TJ}/T_A	1.60	1.59
T_{TJ} , K	477.4	472.9
U_j , mps	329.6	328.0
Re_D	0.567	0.568
p_A , kPa	98.165	97.359
T_A , K	298.8	296.6
D_j , mm	50.8	50.8
X/D_j	3.00	3.00
Z/D_j	0.00	0.00
ΔY , mm	0.8	0.8
	No T/C	T/C

Figure B.134 Horizontal Mach Number Profile, With and Without Thermocouple, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1.6$, $X/D=3$

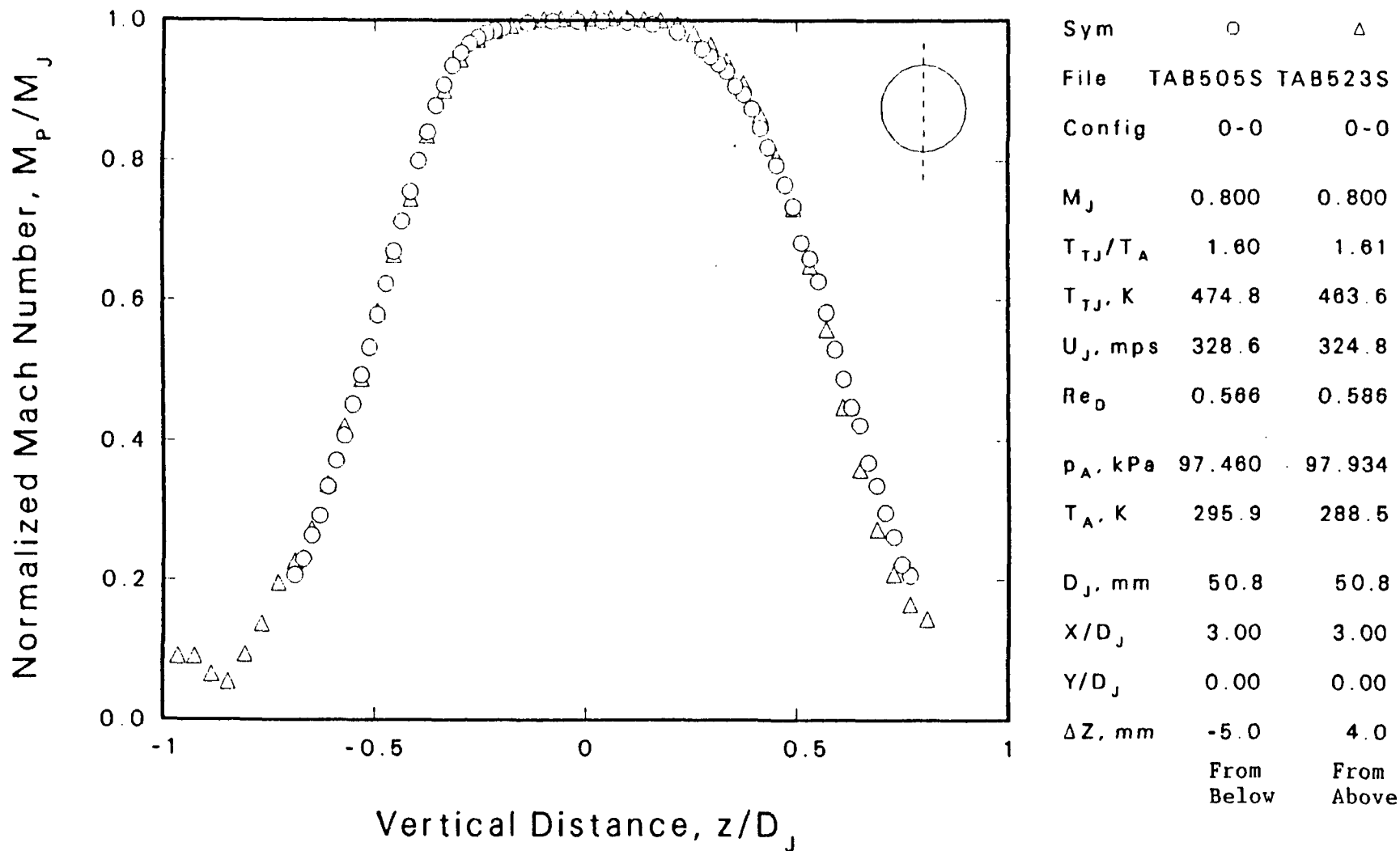
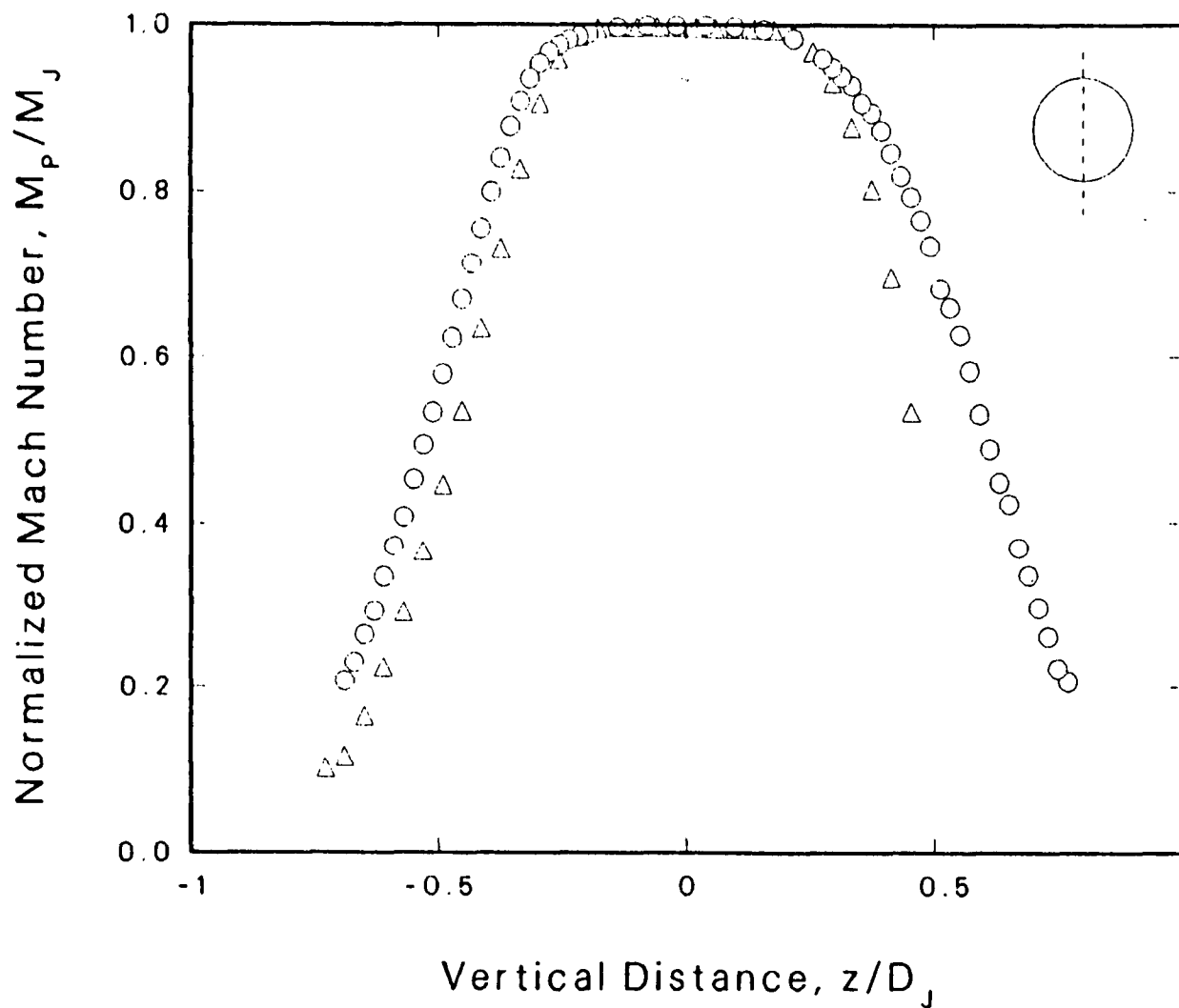


Figure B.135 Vertical Mach Number Profiles from Below and Above the Circular Nozzle, $M_j=0.8$, $T_j/T_0=1.6$, $X/D=3$



Sym	○	△
File	TAB505S	TAB508S
Config	0-0	0-0
M_j	0.800	0.800
T_{TJ}/T_A	1.60	1.59
T_{TJ} , K	474.8	469.8
U_j , mps	328.6	327.1
Re_D	0.566	0.577
p_A , kPa	97.460	97.934
T_A , K	295.9	294.9
D_j , mm	50.8	50.8
X/D_j	3.00	3.00
Y/D_j	0.00	0.00
ΔZ , mm	-5.0	-8.0
	Kiel	Boundary Layer

Figure B.136 Vertical Mach Number Profiles Measured by Kiel and Boundary Layer Probes, Circular Nozzle, $M_j=0.8$, $T_i/T_0=1.6$, $X/D=3$

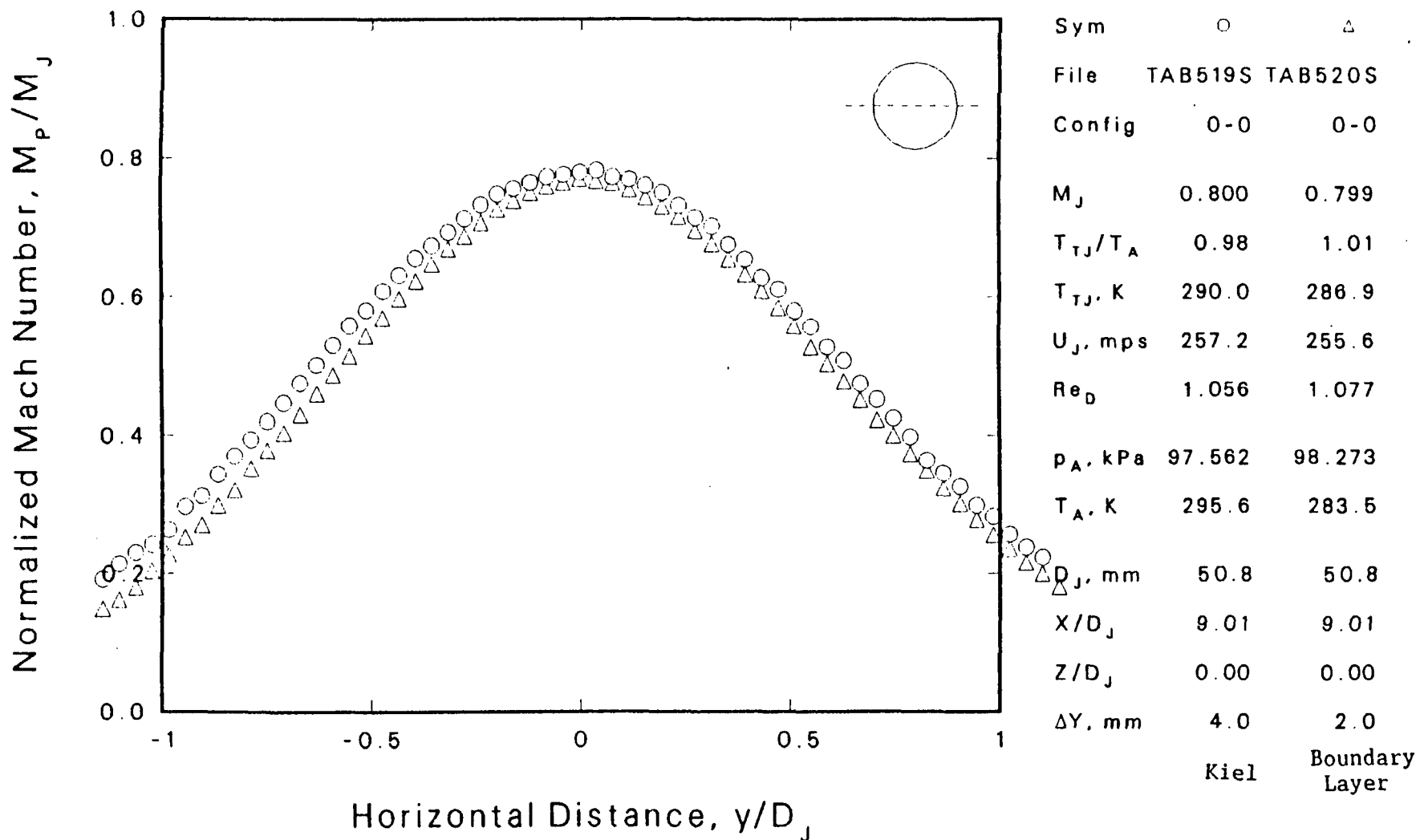


Figure B.137 Horizontal Mach Number Profiles Measured by Kiel and Boundary Layer Probes in the Absence of Tones, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1.59$, $X/D=9$

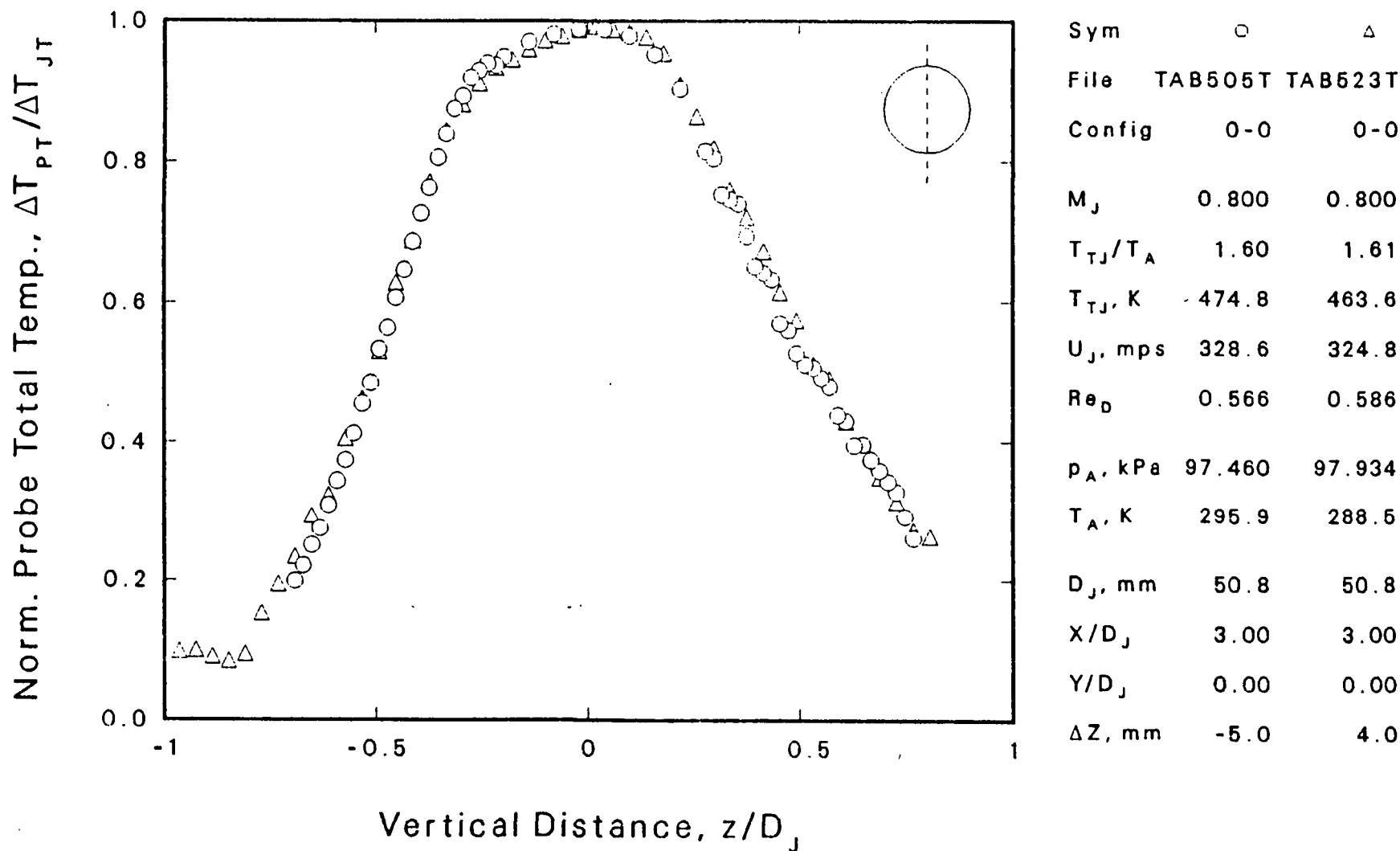
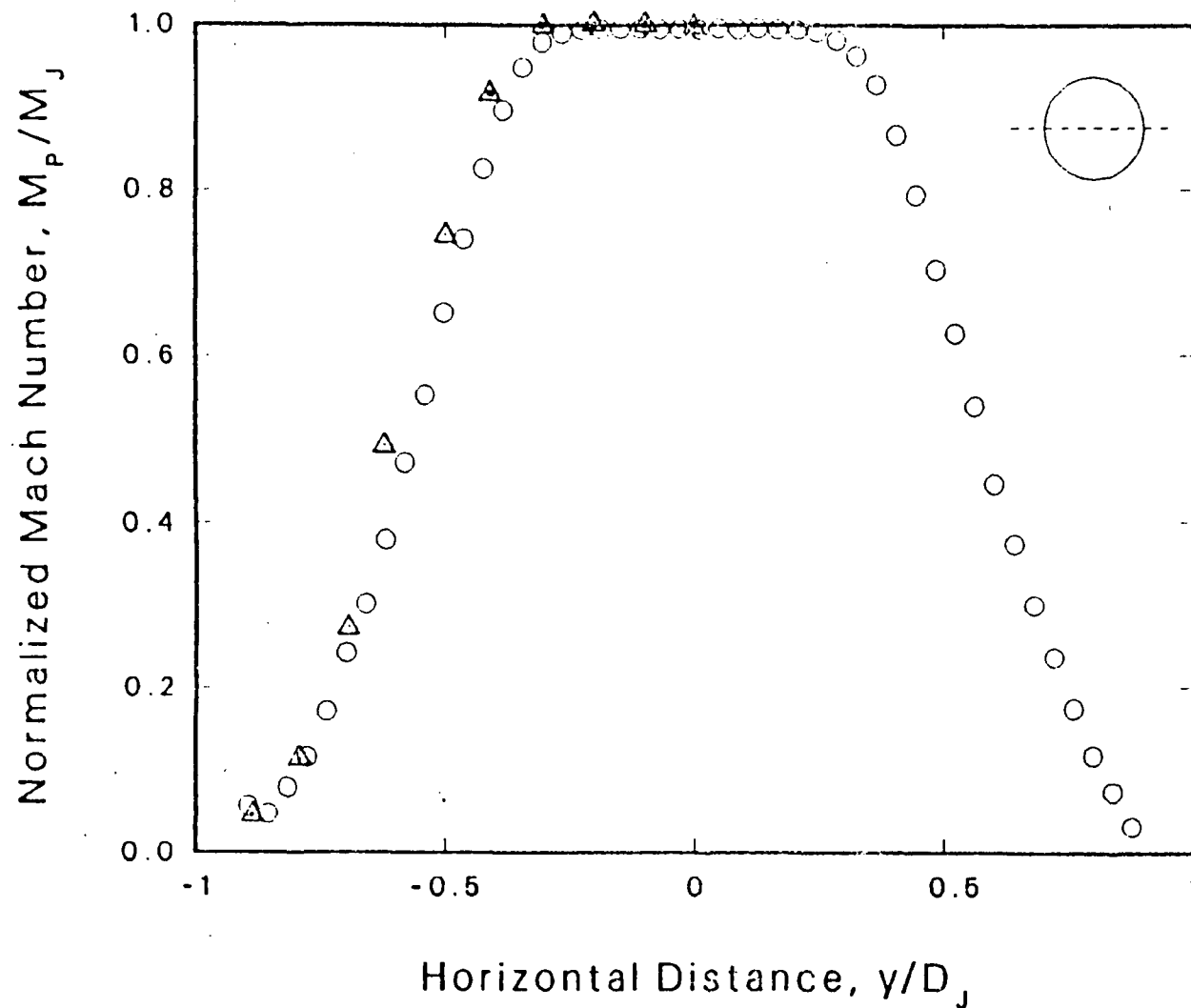
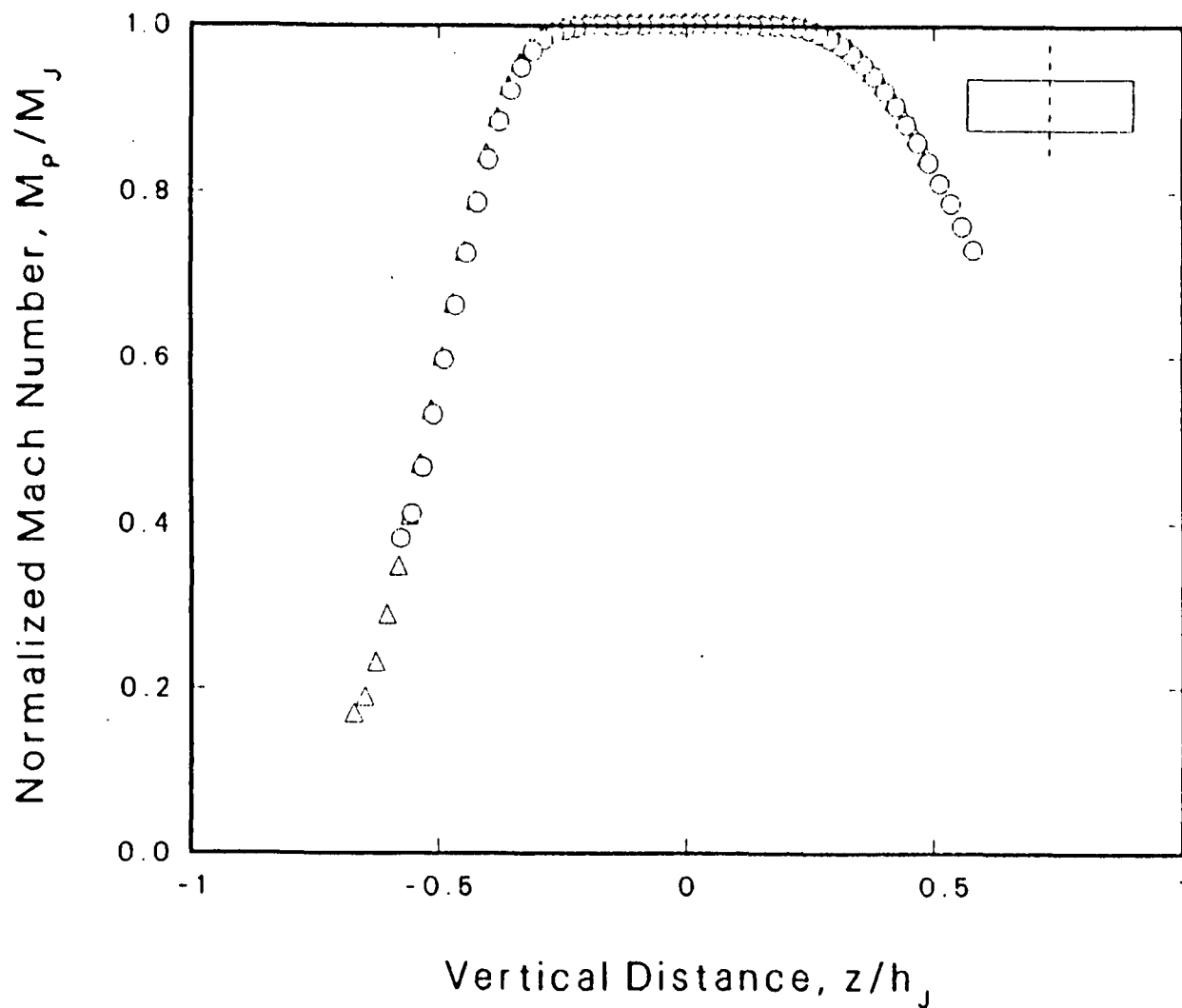


Figure B.138 Vertical Temperature Profiles Measured from Below and Above by the Kiel Probe, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1.6$, $X/D=3$



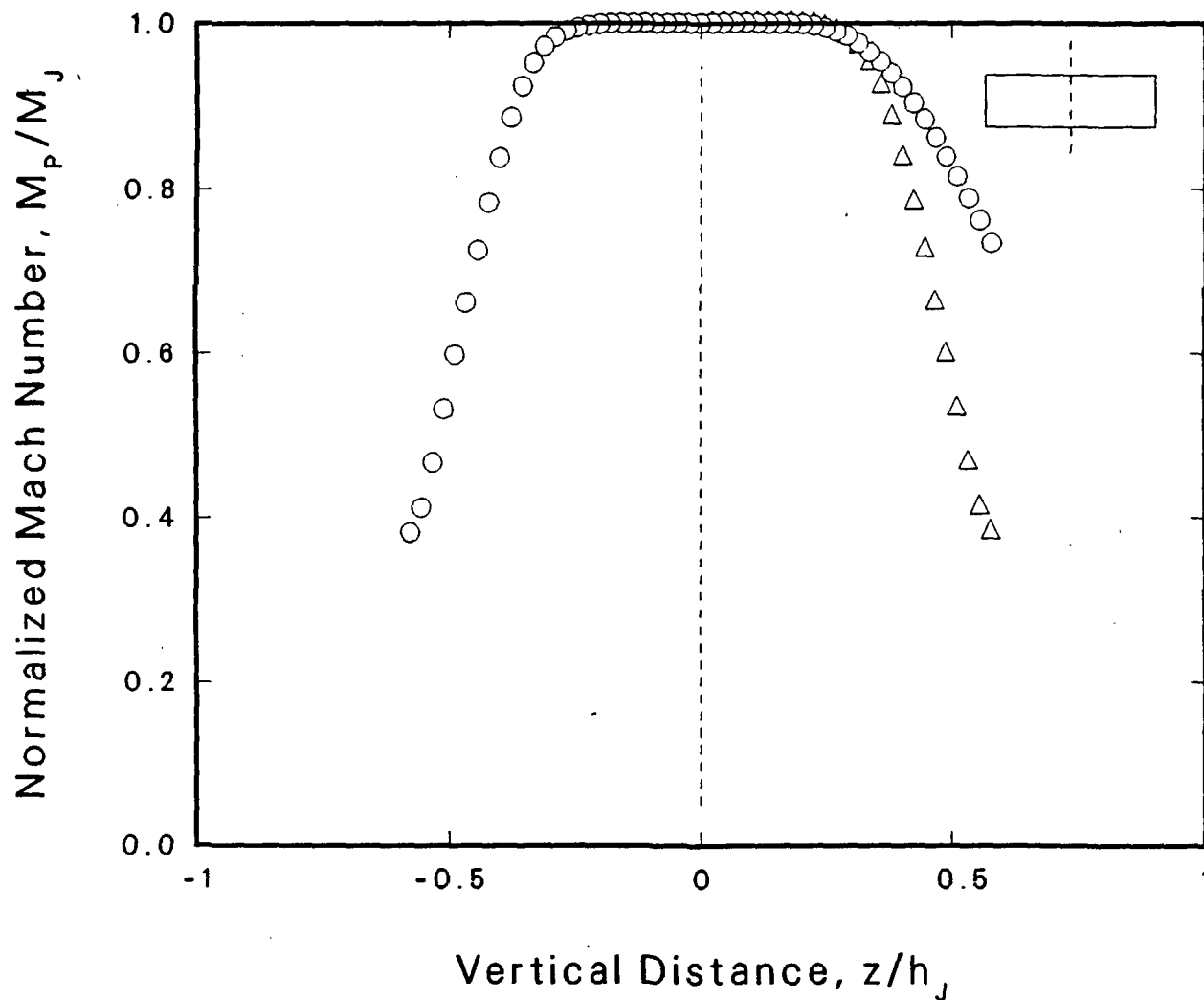
Sym	○	△
File	TAB510S	LV
Config	0-0	
M_j	0.580	
T_{Tj}/T_A	0.99	
T_{Tj} , K	290.8	
U_j , mps	192.1	
Re_D	0.719	
p_A , kPa	98.781	
T_A , K	293.1	
D_j , mm	50.8	
X/D_j	3.00	
Z/D_j	0.00	
ΔY , mm	0.5	
Boundary Layer		

Figure B.139 Horizontal Mach Number Profiles Measured by Boundary Layer Probe and LV, Circular Nozzle, $M_j=0.8$, $T_j/T_0=1.6$, $X/D=3$



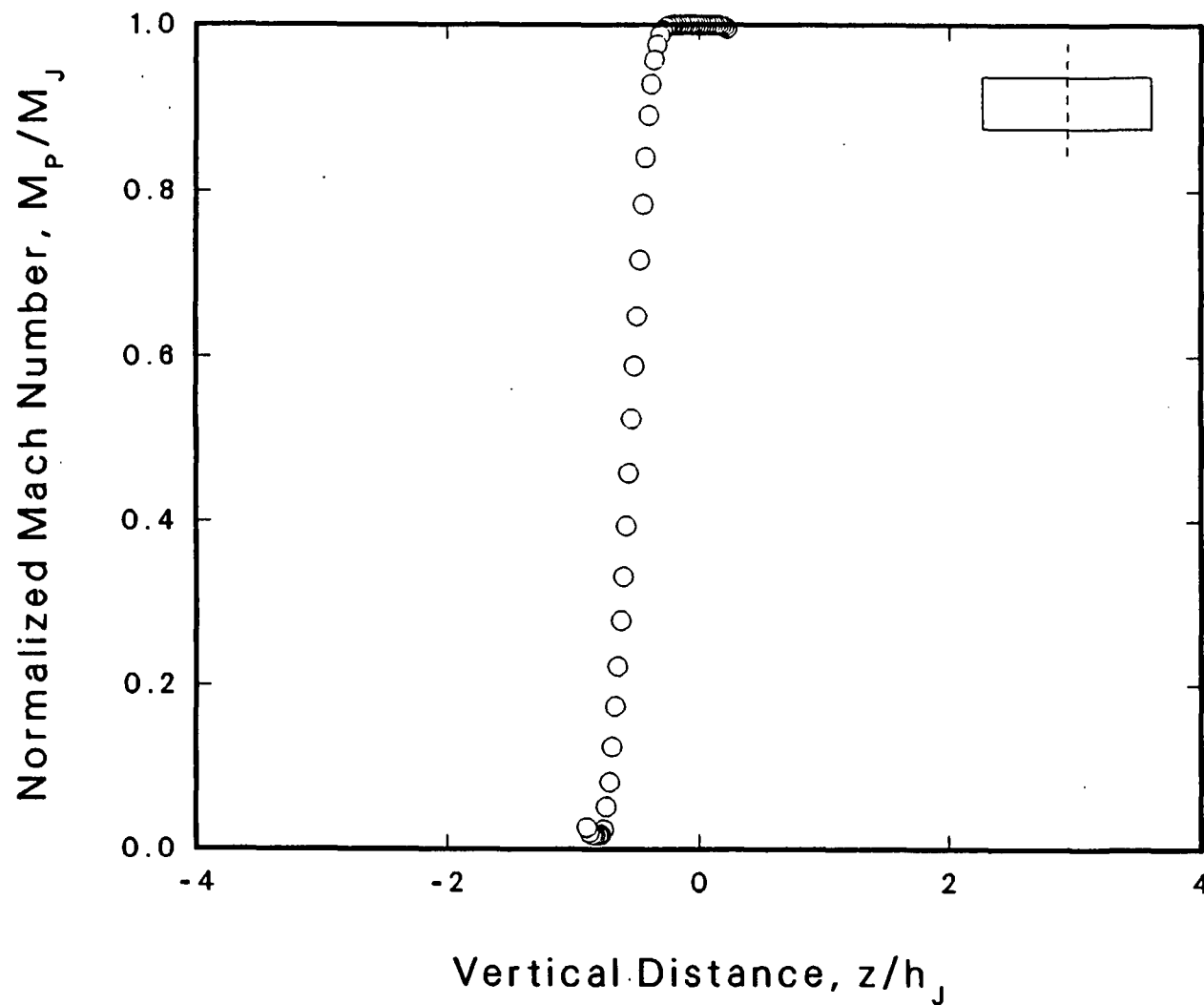
Sym	O	Δ
File	tab049s	tab053s
Config	0-0	0-0
M_j	0.800	0.800
T_{TJ}/T_A	0.99	0.98
T_{TJ} , K	291.3	292.7
U_j , mps	257.9	258.5
Re_{D_e}	1.057	1.047
Re_h	0.468	0.464
Re_w	1.871	1.854
p_A , kPa	98.171	97.867
T_A , K	294.2	300.0
De_j , mm	50.8	50.8
X/De_j	1.00	1.00
Y/w_j	0.00	0.00
ΔZ , mm	0.0	2.1

Figure B.140 Effect of Nozzle Inversion on Vertical Mach Number Profile, $M_j=0.8$, $T_j/T_0=1$, $X/D=1$



Sym	○
File	TAB048S
Config	0-0
M_j	0.800
T_{Tj}/T_A	1.00
T_{Tj} , K	290.7
U_j , mps	257.5
Re_{De}	1.059
Re_h	0.469
Re_w	1.875
p_A , kPa	98.138
T_A , K	289.7
De_j , mm	50.8
X/De_j	1.00
Y/w_j	0.00
ΔZ , mm	0.0

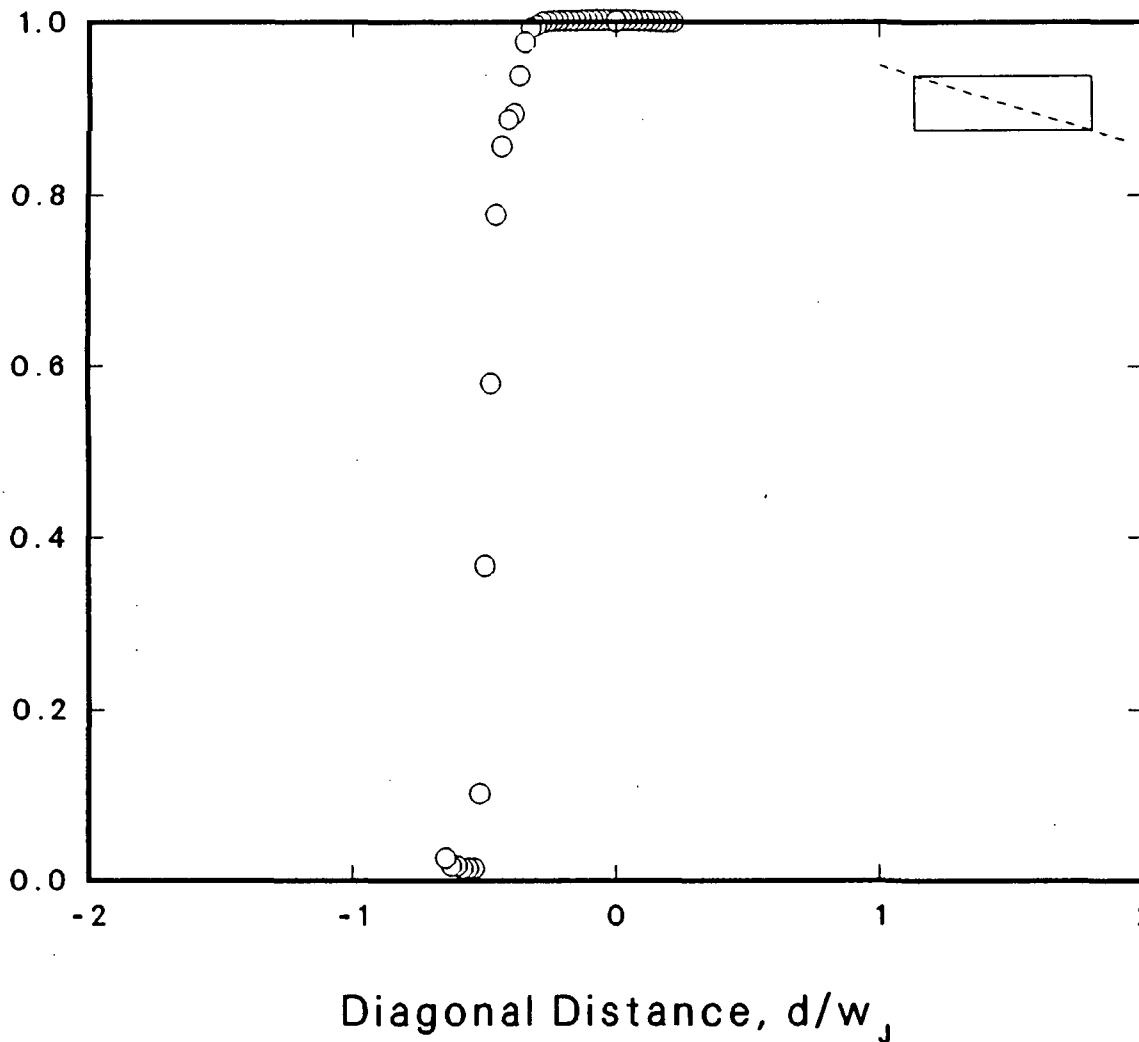
Figure B.141 Symmetry of Vertical Mach Number Profile,
 $M_j=0.8$, $T_j/T_0=1$ $X/D=1$



Sym	○
File	TAB135T
Config	0-0
M_J	0.796
T_{TJ}/T_A	0.98
T_{TJ}, K	286.7
U_J, mps	254.7
Re_{De}	1.078
Re_h	0.477
Re_w	1.908
p_A, kPa	98.612
T_A, K	291.6
De_J, mm	50.8
X/De_J	1.00
Y/w_J	0.00
$\Delta Z, mm$	0.0

Figure B.142 Baseline Vertical Mach Number Profile
 $M_J=0.8$, $T_J/T_0=1$, $X/De=1$

Normalized Mach Number



Sym	○
File	TAB136T
Config	0-0
M_j	0.799
T_{TJ}/T_A	1.00
T_{TJ}, K	285.2
U_j, mps	254.9
Re_{De}	1.082
Re_h	0.479
Re_w	1.975
p_A, kPa	97.901
T_A, K	284.6
De_j, mm	50.8
X/De_j	1.00
Z/h_j	0.00
$\Delta Y, mm$	0.0

Figure B.143 Baseline Diagonal Mach Number Profile
 $M_j=0.8$, $T_j/T_0=1$, $X/De=1$, -14 Deg

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16. Abstract The objective of the study described here is to determine the effects of mechanical protrusions on the jet mixing characteristics of rectangular nozzles for heated and unheated subsonic and supersonic jet plumes. To accomplish these objectives, the characteristics of a rectangular nozzle of aspect ratio 4 without the mechanical protrusions were first studied. Intrusive probes were used to make the flow measurements. Possible errors introduced by intrusive probes in making shear flow measurements were also examined. Several scaled sizes of mechanical tabs were then tested, configured around the perimeter of the rectangular jet. Both the number and the location of the tabs were varied. From this, the best configuration was selected. The following general conclusions were derived: (1) intrusive probes can produce significant errors in the measurements of the velocity of jets if they are large in diameter and penetrate beyond the jet center; (2) rectangular jet without tabs, compared to circular jets of the same exit area, provide faster jet mixing; and (3) further mixing enhancement is possible by using mechanical tabs.					
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